CROWOOD AVIATION SERIES

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All contributions, however large or small, have played an equal part in helping to produce what I hope is a fitting tribute to one of the world's greatest aircraft.

Martin W. Bowman
Norwich, December 1999

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Introduction

The Boeing Company was founded by William E. Boeing, the son of a wealthy timberman. At the age of thirty-four, Boeing took up flying for his own amusement, but after a couple of rides he became convinced that he could build a better aeroplane. He and Cdr G. Conrad Westervelt, a Navy officer assigned to engineering work at a Seattle shipyard, Washington, decided to build a pair of seaplanes. By December 1915, an aeroplane called the 'B & W Seaplane' was under construction in a hangar on the east shore of Lake Union. *Bluebird*, the first B & W, was completed in early 1916, marking the modest beginning of aircraft production at the Boeing Company; it flew for the first time on 29 June.

Although aircraft work had been in progress since 1915, corporate identity was not achieved until the Pacific Aero Products Company was incorporated on 15 July 1916, and a new airline subsidiary, Boeing Air Transport, was formed. On 26 April 1917 the name was changed to The Boeing Airplane Company. The Seattle factory redesigned their 1925 Model 40 to take the new, air-cooled Wasp engine, and built twenty-four Model 40As in just six months, ready for service with the new airline. Its competitors, meanwhile, continued to use the heavier, water-cooled Liberty-engined aircraft for mail service. In addition to having space for 1,200lb (544kg) of air mail, the Model 40A had room for two passengers in a small cabin ahead of the pilot's open cockpit; later models carried four passengers. A total of eighty-two Model 40s were built. Their introduction signalled the beginning of regular commercial passenger service over long distances, and served as the vehicle for the first regular passenger and night mail flights.

The success of the passenger operations with Model 40s on the San Francisco–Chicago route encouraged expansion of the business through the addition of larger aircraft designed specifically for passenger convenience and comfort. In 1928 Pacific Air Transport (PAT), a San Francisco to Seattle airline, was purchased and the two airlines were merged to become 'The Boeing System'. The first of four Model 80 tri-motor biplanes, the last word in air transportation, was delivered to Boeing Air Transport in August 1928, only two weeks after its first flight. Twelve passengers – and later, eighteen – were carried in a large cabin provided with hot and cold running water, a toilet, forced air ventilation, leather upholstered seats and individual reading lamps. The needs of a dozen or more passengers during long flights soon indicated the desirability of a full-time cabin attendant who could devote all his/her attention to their comfort. While some European airlines used male stewards, Boeing Air Transport hired female registered nurses who became the first of the now-universal stewardesses. The pilot and co-pilot were enclosed in a roomy cabin ahead of, and separate from the passenger cabin.

Boeing, meanwhile, expanded rapidly. In February 1929 it acquired the Hamilton Metalplane Co. of Milwaukee, Wisconsin, and that summer established a Canadian subsidiary (Boeing Aircraft of Canada) in Vancouver, Canada, where it began building C-204 flying boats. A powerful holding

company was formed with the merger of the Boeing airplane and airline operations and Pratt & Whitney, a leading airplane engine manufacturer, Hamilton Aero Manufacturing Co., and another airplane manufacturer, Chance Vought Corporation, to form United Aircraft and Transport Corporation. Each company continued to produce its own specialized product under its own name, while the airlines operated under their own names within a holding company known as United Airlines. Three airlines were acquired and added to the existing operation, while the manufacturing companies Sikorsky Aviation and Standard Steel Propeller Co. were bought up. On 1 April 1938 the Boeing Aircraft Company bought the Wichita (Kansas)-based Stearman Aircraft Co., to create the Stearman Aircraft Division (renamed the Wichita Division in 1941).

When markets for new airplane designs developed, Boeing was ready with new models and processes. It was the first American manufacturer to use welded steel tubing for fuselage structure, a feature that soon became standard throughout the industry until generally replaced by monococque sheet-metal structures in the mid-1930s. Boeing again demonstrated its technological leadership by introducing this new construction, matched to aerodynamically advanced airplanes, in both commercial and military production with the Monomail, B-9 and 247 models of 1930–33.

The all-metal Model 200 Monomail mail and cargo carrier first flew on 6 May 1930: it was one of the most revolutionary airplanes in commercial aviation history. Designed initially as a combination mail and passenger airplane, its increased performance resulted from structural and aerodynamic refinements, not from the addition of brute horsepower. The traditional biplane design with drag-producing struts and wires was replaced by a single, smooth, all-metal low wing of clean cantilever construction. The wheels were retracted into the wing during flight, and the drag of the air-cooled 'Hornet' engine was greatly reduced by enclosing it in a newly developed antidrag cowling. However, the Monomail's sleek aerodynamic design was too advanced for the powerplants of the day. Efficient use of its full performance range required a variable-pitch propeller, and when one was eventually installed, the aircraft was already on the verge of being replaced by the newer, multi-engined designs it had inspired.

Boeing Models 214 and 215, which became the US Army Y1B-9 and YB-9, were logical military developments of the Monomail. Boeing embarked on the two B-9 projects as a private venture in the hope that they would produce the same performance advance in the area of heavy bombers as the Monomail had done in the commercial sector; but the type was not ordered in quantity. The B-9 did, however, prove a major advance in bomber design, and it greatly influenced the Model 247, the first airliner produced in quantity by Boeing.

An unprecedented decision was made to completely re-equip the Boeing Air Transport System with the innovative new twelve-seater transport, and an order for sixty Model 247s was placed while the design was still in the mockup stage. The Model 247 was the first all-metal, streamlined monoplane transport. It was powered by two supercharged Pratt and Whitney 550hp S1D1 Wasps (the first time superchargers had been used on a transport type), and featured a retractable landing gear, an enclosed cabin, auto-pilot, trim tabs and de-icing equipment.

In 1934 Congress passed legislation which forced aircraft and engine manufacturers to end all their links with airline operations. (On 26 September, a government trust-busting suit, which divorced airplane and engine manufacturers from airline operations, had separated United Aircraft's airline and manufacturing activities, and the Boeing Aircraft Company – renamed from the Boeing Airplane Company, and a separate entity from Boeing Air Transport – had pulled out of United. The Boeing Aircraft Company resumed independent operation and moved into the bomber business.)

In the 1930s it was accepted that a formation of unescorted bombers could get through to their target if they were properly arranged and adequately armed. During air manoeuvres in 1933, pursuits repeatedly failed to intercept the bombers, and there was even talk of eliminating pursuits altogether. Funds for new aircraft were very limited, and mostly it was manufacturers who funded new developments which in turn might attract orders from the military. (By 1934, Model 247 production was winding down, and the only business Boeing had was unfinished contracts for P-26A, the only single-engined fighters built by Boeing, and P-26C fighters. In August, 1,100 of its 1,700 workforce were laid off: cash on hand was barely $500,000.)

Boeing's first bomber development, in 1934, was the massive Model 294, or the XBLR-1 (experimental bomber, long range), which became the XB-15. That same year the Air Corps issued a specification for a 'multi-engined' bomber, but manufacturers would have to build prototypes at their own expense. Although the term 'multi-engined' generally meant two engines, the four-engined Model 299 was already in the design stage, and so on 16 September 1934, Boeing decided boldly to invest $275,000 in the Model 299. The new design, which was to become famous in World War II as the B-17, incorporated many lessons learned with the X-15, B-9 and Model 247. Powered by four 750hp Pratt and Whitney 'Hornet' radials, it would carry all bombs internally and accommodate a crew of eight. Thirteen service-test Y1B-17s went into service with the AAC and established many long-distance records, earning Boeing a well deserved reputation for rugged construction and reliable operation.

Enter Juan Trippe

One of Boeing's biggest pre-war customers, who would prove fundamental to the success of Boeing airliners for decades to come, was Pan American Airways, headed by Juan Terry Trippe, a wily, very clever businessman who had first learned to fly in World War I. Trippe followed a series of successful mergers by creating Pan Am in 1928, after winning highly profitable air-mail routes to the Caribbean. He then followed this with another merger in 1930, which led to Pan Am gaining lucrative contracts to carry air mail on his Fokker Tri-Motors and Sikorsky S-38 flying boats between the US and South America. In 1932 Pan American ordered its first four-engined flying boats when it took delivery of three Sikorsky S-42s and three Martin M-130s for forty-eight passengers. Soon, delivering air mail accounted for three-quarters of the company's revenues.

In the mid-1930s Trippe expanded Pan Am's operations to include the Pacific. Pan American Airways was the first big carrier to fly regular long-distance flights, and quickly became the world's largest passenger airline as well as air-mail carrier. In 1936 Trippe ordered twelve Boeing B-314 flying boats, called 'Pullmans of the sky'. Each was capable of carrying seventy-four passengers and was fitted out with sleeping berths and dining areas. All twelve flying boats were

Early in 1936 the beautiful Model 314 was designed to meet a specification issued by Pan American Airways for a long-range, four-engined flying boat capable of carrying seventy-four passengers and a crew of six to ten. Boeing signed an agreement on 21 July 1936 for six 314s, or 'Clippers' as they were known, and they were all delivered between January and June 1939. Six 314As followed for PAA, with more powerful engines and provision for three extra passengers, and the first six 314s were brought up to the same standard. NC18602 42-88632 *California Clipper* (pictured) was operated by the US Army in World War II. The last flight of a Pacific Pan Am Clipper was on 8–9 April 1946 when NC-18606 *American Clipper* took off from Honolulu for Mills Field, San Francisco. The last Atlantic flight was on 24 December 1945. Post-war, the 'Clippers' were replaced by landplane types. Boeing

(*Below*) The Model 377 Stratocruiser was an airline development of the C-97, and fifty-six were built at Seattle between 1947 and 1949. Pan American World Airways was the largest Stratocruiser operator, with twenty-nine Model 377s; Model 377-10-26 N1030V *Clipper Southern Cross* is pictured. Ten PAA -26s were modified to Super Stratocruisers by adding an additional 450 gallons (1,909 litres) of fuel to permit non-stop flights between New York and London and Paris. Stratocruisers offered the last word in passenger comfort and fifty-five to a hundred-plus people could be accommodated according to the length of the route and the type of service. A complete galley for hot meal service was located near the tail, and men's and women's washrooms separated the forward compartments from the main passenger cabin, where a spiral stairway led to a deck lounge on the lower deck behind the wing. When fitted out as a sleeper aircraft, the 377 was equipped with twenty-eight upper and lower berth units plus five seats. Boeing

called 'Clippers', and had romantic names such as *California Clipper* and *Pacific Clipper*; collectively they were known as 'China Clippers'. By the eve of World War II Pan Am World Airways were flying to London via Newfoundland, and Lisbon and Marseilles via the Azores. During the war, Pan Am became the largest civilian troop carrier and almost all its energy was directed to assisting the war effort. Post-war, Trippe invested heavily in new aircraft and soon they were flying to every continent.

As history was to show, Trippe, always committed to revolutionizing commercial aviation, would take every opportunity to invest in new aircraft, and it was Boeing that would benefit most in the post-war years and beyond.

Boeing development of a jet bomber began in 1943, and the Model 450 was approved in April 1946. 46-065, seen here being rolled out on 12 September 1947, was the first of the two XB-47 prototypes to fly, on 17 December 1947. The first steps towards the 747 began with the B-47 Stratojet, with its podded engines and new thin wing, swept back at an angle of 35 degrees at the quarter-chord point. The second XB-47 flew in July 1948 with the more powerful General Electric J47 powerplant of 5,200lb (2,363kg) of thrust in place of the earlier J35s of only 3,750lb (1,705kg) of thrust. Altogether 2,032 B-47s were built, including 1,373 by Boeing. Boeing

All-Jet Airliners Become Reality

Following World War II, Boeing re-entered the commercial airliner market, starting in 1947 with the Model 377 Stratocruiser which was produced side by side with B-50s on the Seattle production lines until 1949. Throughout the late 1940s and 1950s, the Boeing Aircraft Co. faced a challenge from other giants in the US aviation industry, notably Douglas, first with its DC-6, 6A, and 6B designs, and Lockheed, initially with its Constellation, and then Super Constellation designs, for pre-eminence in the four-engined turboprop commercial transport market.

Boeing entered the jet age with the roll-out on 12 September 1947 of the XB-47 experimental pure-jet bomber prototype. It could be said that the first steps towards the 747 began with the B-47 Stratojet, with its podded engines and new thin wing, swept back at an angle of 35 degrees at the quarter-chord point, although the bomber was originally conceived by Boeing engineers as a straight-wing design with buried engines. In part the swept-back wing shape owed much to the German jet designers in World War II. (Three of Boeing's leading engineers, Bert Kineman, George Martin and George Schairer, were part of Operation *Seahorse*, a US exploitation team led by Theodore von Karman, the renowned aeronautical engineer and physicist, which uncovered wind-tunnel data into swept wings at the German Aeronautical Research Institute near Braunschweig at the end of April 1945.) Sweep angles as high as 45 degrees allowed a significant increase in speed by delaying the formation of shock waves as the wing approached the speed of sound. The buried engine layout of the XB-47 was also abandoned after objections from the US Army Air Force regarding its vulnerability and safety. Instead, the six 3,750lb (1,701kg) thrust General Electric J-35 engines were hung under the wings in pods.

Whilst Boeing undoubtedly benefited from the German research into swept-wing design, the company had the added advantage of having its own high-speed wind tunnel which it had finished building in 1944 at a cost of $750,000. This enabled Boeing to test, remedy, and perfect the B-47 swept-wing design, and further exploit its lead in wing technology over other aircraft manufacturers. In appearance, Boeing's final foray into the super bomber business, the B-52 Stratofortress, owed much to the B-47. Another feature of the B-47 which was later to be used on the 747 was the use of a multiple undercarriage layout, which on the B-47 was in tandem. Both the main two-wheel bogies, or trucks, were located on the centreline of the fuselage, ground stability being provided by outrigger wheels that retracted into the inboard nacelles, whilst the 747 was to have several sets of gear beneath the fuselage.

The first of two prototype XB-47s flew from Boeing Field, Seattle, to nearby Moses Lake AFB on 17 December 1947. The second XB-47 flew in July 1948 with the more powerful General Electric J47 powerplant of 5,200lb (2,363kg) of thrust in place of the earlier J35s of only 3,750lb (1,705kg) of thrust. Major production began with the B-47B, which flew for the first time at Wichita on 26 April 1951.

The 707, First of the Mass-Produced Jetliners

Not for the first time in Boeing's illustrious history – and certainly not for the last – the company's next logical step up from the B-47 was to adapt its design to that of a new long-range jet-powered aircraft intended as a military tanker, but with clearly significant commercial possibilities. Of course, this source of development was nothing new in the aviation industry and, as has been seen, it was certainly not a new undertaking for Boeing. The company had long derived some very successful (and some less than successful) commercial designs from its corresponding military conversion programme. In this case though, Boeing would be gambling on a pure-jet airliner for the first time.

When Boeing engineer Wellwood Beall had returned to Seattle from Britain in 1950, he brought news with him that the de Havilland company had developed a medium-range jet airliner called the Comet. Though the British jet never realized its potential, Beall and the other Boeing engineers knew that jet transport would revolutionize air travel. Propeller-driven

In August 1952 Boeing announced plans to invest $16 million to build an entirely new jet-powered transport, the Model 707. The prototype carried the designation 367-80, which Boeing technicians called the 'Dash-Eighty' and the sales personnel, '707'. The 367-80 707 (N70700) (pictured) flew on 15 July 1954. The first customer was Pan Am, under the direction of Juan Trippe, who on 13 October 1955 committed Pan Am to the purchase of twenty 707s. The airline became the first to place the 707 in service, in June 1963. Between 1957 and 1982 Boeing delivered 855 Model 707s in all three versions: the 707-120, the -320 and the -420 intercontinental airliners. No fewer than 725 of these aircraft, delivered between 1957 and 1978, were for commercial use. Boeing

transports such as Boeing's C-97 Stratofreighter were approaching their performance limits, and the combination of high speed and cost efficiency of the jet made long-distance air travel more practical.

Never afraid to take a gamble when the time was right (such a risk had paid off twenty years before with the B-17), in August 1952 Boeing announced that it was investing $16 million of its own money (two-thirds of the company's net profits from the post-war years) to build the prototype of an entirely new jet-powered transport. This was on the assumption that if Boeing did not build it, Douglas probably soon would, and the aircraft was developed by Boeing in secrecy to protect its market. The prototype was designated Model 367-80, to disguise it as merely an improved version of the C-97. The Model 367 Stratofreighter was in production for the

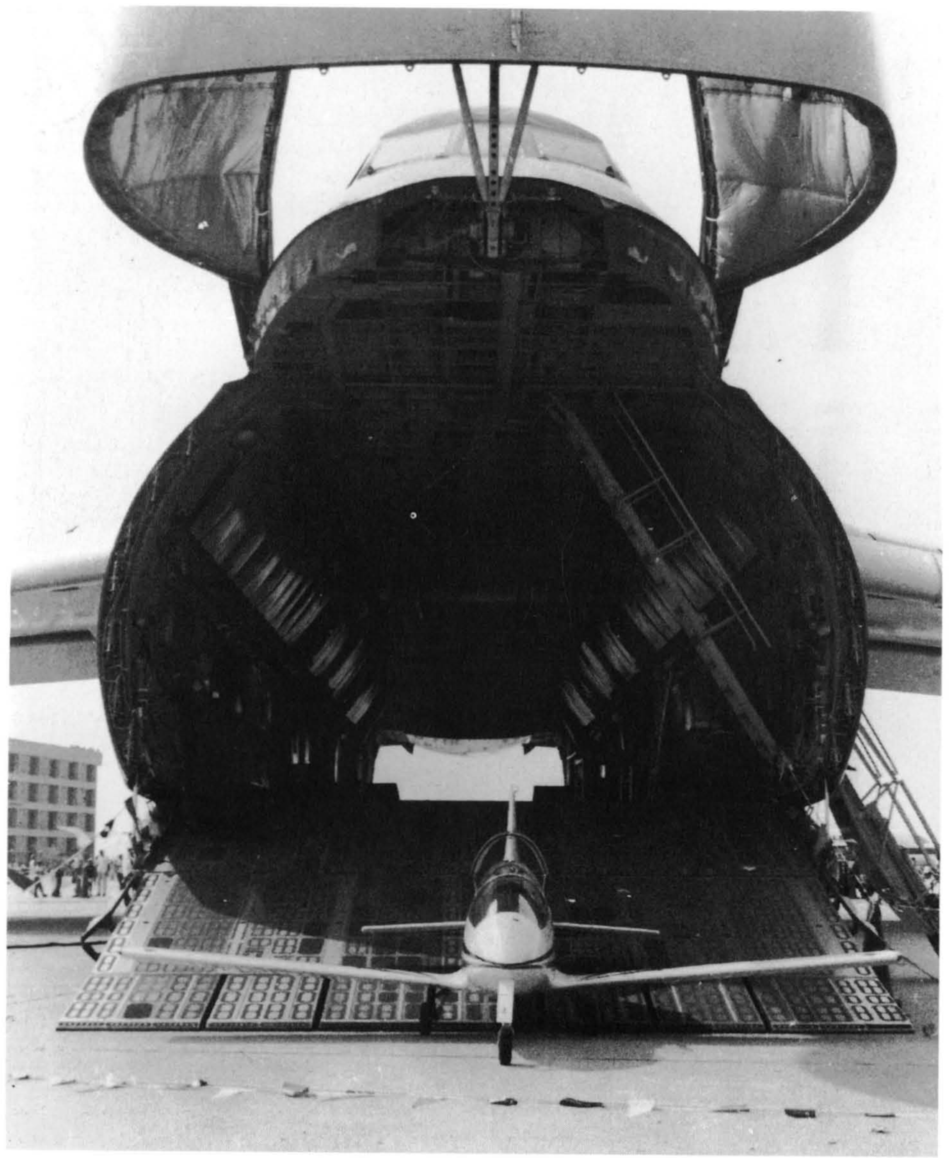
Belatedly Douglas tried to catch up with the Boeing 707, announcing in June 1955 that it was entering the long-range jet transport field with the similar DC-8; but it was too late to mount a serious challenge to the 707. By the end of 1961 just 176 DC-8s had been sold, while Boeing delivered 320 707s and 720s. KLM

air force as the C-97, but the Model 367-80 was so far advanced that it bore no resemblance whatever to the cargo-transport; in fact, '80' referred to the number of study configurations that the Model 367 had finally arrived at. The 'Dash-Eighty', as the Boeing technicians called it, retained the B-47's 35-degree wing sweepback and its podded engine layout, although the latter were no longer hung in a two pairs and two singles arrangement: instead, the six GE turbojets had been replaced by four separately hung Pratt & Whitney JT3s, each capable of 10,000lb (4,536kg) of thrust.

Although for engineering and shop purposes the designation 367-80 was retained by Boeing, the number 707 which was later applied to the prototype came about as a result of Boeing's sequential model development numbering system that dates back to 1916. Seven has always been a lucky number throughout the long and distinguished history of the Boeing Company, starting with the Model 247 and continuing to the B-47 jet bomber, and the 707, 727 and 737 series commercial airliners. Each was an innovative and far-reaching design which met the technological demands of new and distant horizons and then surpassed them, setting the standard for others to follow. By 1951, the Boeing model numbers had been divided into large blocks among the company's various product lines, so the number assigned to the anticipated production versions of the 'Dash-Eighty' was in the 700 block (the 400, 500, and 600 series were already assigned to missiles and non-aircraft blocks). The number 707 chosen for the 367-80 thereby established the numbers for the 727, 737 and 747 series that would follow and become famous.

The 707's chief engineer was Maynard Pennell, a specialist in airframe structures, who after World War II had joined Boeing from Douglas, where he had formed an affinity for commercial airliners. Pennell was determined to steer Boeing, which traditionally relied on producing bombers, towards becoming a prime supplier of jet airliners. He set out to bring together all that was best in Boeing's high-speed, subsonic jet development, gained from building bombers, and to use it to help devise the company's first commercial jetliner. Pennell and colleague Jack Steiner, another advocate of jet airliners who went on to

Contracts for the Model 727-100 short-to-medium-range jet were signed in December 1960; this was to replace the many piston and turboprop aircraft in service. The first 727, designated 727-22 (N7001U, for United Airlines), was rolled out at Renton on 27 November 1962. Some 408 727-100s were built. Originally Boeing planned to build 250 727s, but they proved so popular that a total of 1,832 aircraft – through -100, -100C, and -200 – were produced at the Renton plant. The 737, which appeared in April 1967, proved another big money-spinner with no fewer than 1,114 -200s (which followed the thirty -100 models) being delivered by August 1988. Boeing



The competition to build the CX-HLS all-new high-capacity airlifter (later named the C-5A Galaxy), which had to be capable of carrying 750 fully equipped troops anywhere in the world, began in 1962 with Boeing competing against Douglas and Lockheed. The project was finally awarded to Lockheed in October 1965. This meant that Boeing could begin development of the 747, and engine manufacturers such as General Electric and Pratt & Whitney could perfect an engine capable of powering Boeing's new airliner. Although Boeing went on to make excellent use of the development potential gained during the abortive airlifter project, subsequent problems associated with the complex C-5A design, and the high cost-overrun, were later mirrored in the 747 programme. Lockheed

design the 727, had first evolved the 473-60C, a half-size airliner version of the B-47. This was never built.

When this failed to convince potential buyers, who preferred instead the propeller-driven Douglas DC-7C, Pennell knew that Boeing had to offer something more than adaptations of military designs. As in the case of the 747 a generation later, Pennell had to demonstrate that by using a combination of Boeing's unquestioned lead in swept-wing technology married to an aerodynamic body, he would produce an airliner so economical and so far ahead of anything else that no airline, no matter how radical the design, could ignore it. Backed by the president of the Boeing Airplane Company, William 'Bill' M. Allen, Pennell and his engineers did precisely that.

The Start of the Jet Transport Era

The American jet transport era can be said to have begun when the 367-80 first flew on 15 July 1954. From this date forward Boeing all but made the long-haul and the short-to-medium-range markets their very own, with a succession of hugely successful air transports. Douglas, ever cautious, belatedly tried to catch up with its new rival, announcing in June 1955 that it was entering the long-range jet transport field with the not dissimilar DC-8; but it was too late to mount a serious challenge to the 707. By the end of 1961 just 176 DC-8s had been sold, while Boeing raced ahead, selling 320 707s and 720s (the 720 being a derivative design of the 707). The first customer was Pan American, a company which, under the steermanship of Juan Trippe, had never been afraid to buy, and to buy big. In September 1955 he committed Pan Am to the purchase of twenty-five Douglas DC-8-31s (later reduced to nineteen), and on 13 October he placed an order with Boeing for six 707-121s; in fact the airline became the first to place the 707 in service, on 26 October 1958. The fact that no other airline in the US dared risk investment in the new jets – especially following the crashes, early in 1954, of two of the first BOAC Comet jet airliners to fly – seemed to spur Trippe on. It is due to Trippe, first and foremost, that the commercial jet-airliner business really took off when it did.

Boeing's big gamble had paid off. Many of the design features – such as the Kreuger leading-edge flap, 14 × 12ft (4 × 3.7m), installed inboard of the outboard engine pods to extend automatically when the main flaps were lowered 9.5 degrees – were adopted for use on later 700 series jetliners, right up to and including the 747.

Between 1957 and 1982 Boeing delivered 855 Model 707s in all three versions: the 707-120, the -320 and the -420 intercontinental airliners, and no fewer than 725 of these aircraft, delivered between 1957 and 1978, were for commercial use. Boeing's smaller medium-range jet transports, the 727-100 and the -200, also outperformed their rivals in numbers built. Originally Boeing planned to build only 250 of the aircraft, but they proved so popular that a total of 1,832 were produced at the Renton plant. Only 153 720s were built, but the 737, which appeared in April 1967, proved to be another big money-spinner with no fewer than 1,114 -200s (which followed the thirty -100 models)

By August 1965 a preliminary 747 design group had been formed, followed by project authorization in March 1966. A firm design proposal was offered to the airlines in early 1966. The vast difference in size between the 707 and the 747 is never better illustrated than in this photo of the two famous airliners at Seattle. Boeing

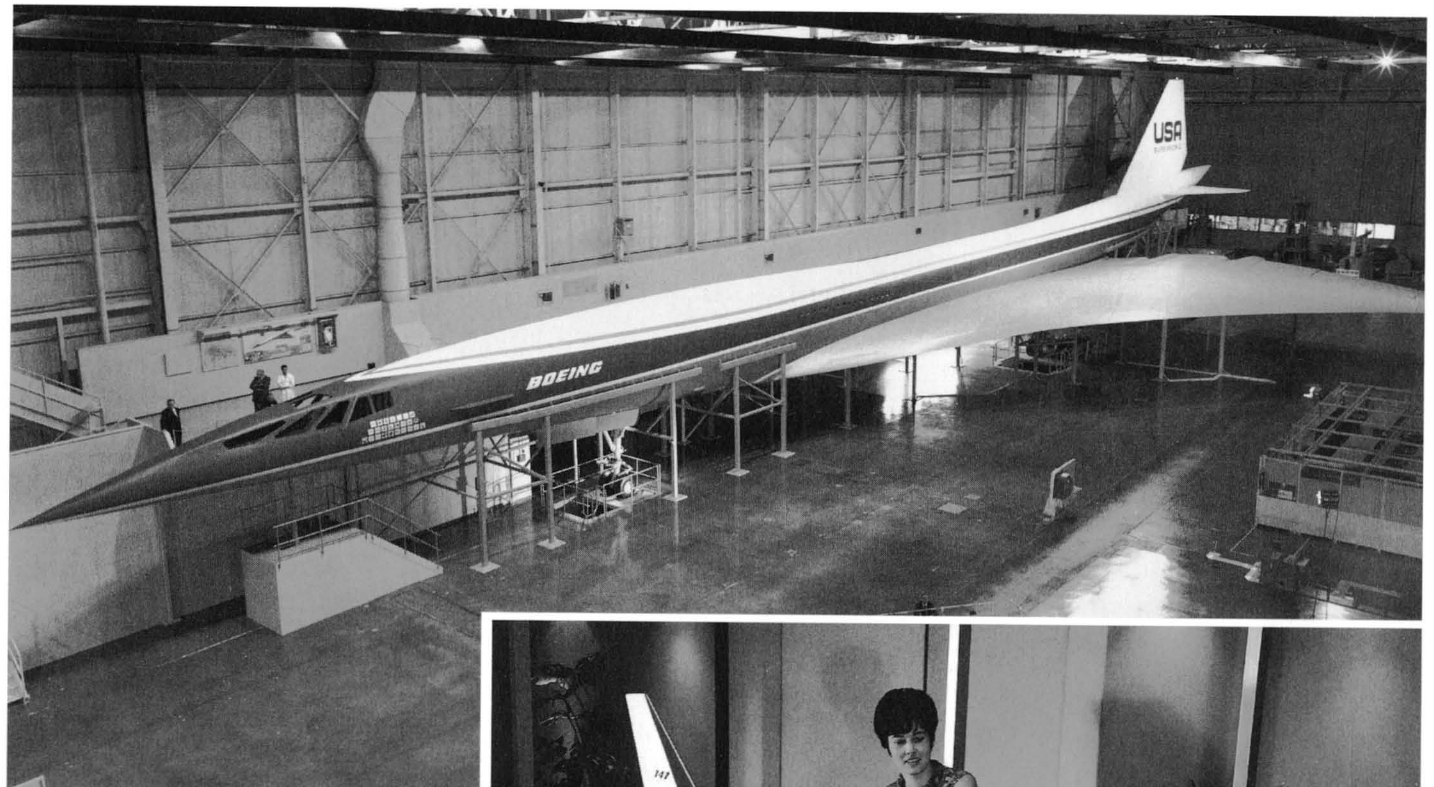
being delivered by August 1988. Ultimately the 737 family (the 737-300 entered production in March 1981) outstripped sales of the Douglas DC-9 and became the world's best-selling jet airliner.

747: Queen of the Skies

If the introduction of the 707 had been innovative, the appearance of the 747, the first of the giant jetliners, had its inception in the early 1960s when market research indicated the need for a much larger capacity subsonic transport to cope with the growing passenger and cargo traffic of the 1970s. Boeing had always maintained its position as a leading supplier of commercial aircraft, backed by a safety net that if all else failed, its financial and managerial risk-taking initiative could always be vindicated by converting a design to meet a military requirement. The last time that risk-taking had occurred on this scale was when the company went out on a limb with its Model 299, which only eventually emerged as the famous wartime B-17 after a protracted and nerve-racking development phase when its competitors prospered for a while with less innovative designs (namely the B-18 Bolo and the B-23 Digby – *see B-17* by the same author). Privately funded, the Flying Fortress, in turn, led to airliner derivatives. Now, thirty years on, the 747, like its famous forbear, was to be built using company funds – although there was no immediate prospect of a military derivative to placate the accountants if the figures did not break even. This at least had been an option with the ground-breaking 707, the last commercial design to break the mould in airline transportation.

By August 1965, a preliminary 747 design group had been formed, followed by project authorization in March 1966. A firm design proposal was offered to the airlines in early 1966. A logical outgrowth of the Boeing 707 series, the 747 not only built on the reputation of its forbears, but improved the breed to such a degree that a new name, 'Jumbo Jet', was coined by the press – and the name stuck. There had never been anything quite like the Jumbo Jet, and even the nickname rang alarm bells in competitors' hearts – even though at Boeing the 747, as first conceived, was seen only as a larger subsonic 'stop-gap' until the Utopian daydream of the supersonic jet arrived on the horizon. Of course the Anglo-French Concorde has carved a supersonic niche all of its own, but the 747 has achieved what no other airliner, supersonic or otherwise, could ever have hoped to achieve: it has opened up global air travel for the common man at prices undreamt of in the 1940s and 1950s, when transatlantic travel was the preserve of the rich and famous.

Everything about the 747 was larger than life, not least the development cost. The prize: untold riches and undreamt of capacity that no other plane maker could really challenge or meet, either technologically or financially. Unhappily for them, if the new wide body succeeded, they would have to compete in an arena even more unfamiliar to them than the one that now confronted Boeing. As events were to prove, ultimately the only alternatives for Boeing's competitors were to merge, and/or to diversify into other markets and leave the Seattle giant to make the gamble, and the running.



(Above) **As first conceived, the 747 was seen only as a larger subsonic 'stop-gap' until in the late 1970s an anticipated 1,250 supersonic (SST) jets – such as the Boeing Model 733, 2707-200, seen here in mock-up form – took over the intercontinental passenger market completely; this left the 747s to be converted for use as large freighters.** Boeing

(Right) **As this model shows, the 747's single deck design and the cavernous cargo-hold could take two 8 × 8ft (2.4 × 2.4m) containers side by side. Pan Am argued repeatedly for the main deck to have a hinged nose section to permit straight-through cargo loading.** Boeing

Although the Anglo-French Concorde – pictured taxi-ing past 747-200 City of Derby **at London-Heathrow in October 1988 – has carved a supersonic niche all of its own, the anticipated supersonic era never materialized. The 747 meanwhile opened up global air travel for the common man and made the market its own.** Author

CHAPTER ONE

B747-100, The Start of It All

'The risks of the 747 are several times greater than in any of our previous commercial ventures.'

William McPherson Allen, Chairman, Boeing Aircraft

Boeing president, William M. Allen (left) arm-in-arm with Juan T. Trippe, chairman of Pan Am. It is due to Trippe, first and foremost, that the commercial jet airliner business really took off when it did. He provided the impetus which enabled Boeing's big gamble to pay off. Boeing

Throughout aviation history some of those designs which failed to enter full-scale production, or which lost out to rival models, have been successfully reinvented to emerge as the format for a completely new type of aircraft. So it was with the 747, whose origins can be traced back to the early sixties when the US Air Force Strategic Air Command sought an all-new high-capacity airlifter to increase significantly its airlift capacity in south-east Asia and throughout the world. In 1962 Project *Forecast* was established to gather data from academia and aerospace companies on the possibilities of giant airlifters and engine technologies to power them. At the same time the air travel industry was growing at a staggering 15 per cent per year, and it was obvious to carriers such as Pan Am and to aircraft companies such as Boeing and Douglas, that the 707 and DC-8 would have to be enlarged or even replaced by much larger commercial types.

The competition to build the all-new high-capacity airlifter, now named the CX-HLS, began in 1962. Established rivals Boeing, Douglas and Lockheed immediately announced their intention to enter designs, which had to be capable of carrying 750 fully equipped troops anywhere in the world. Equal emphasis was of course placed on engine manufacturers General Electric (GE) and Pratt & Whitney, who had to design and build massive powerplants capable of around 40,000lb (18,144kg) thrust per engine. The turbojet had been the main powerplant used to power airliners such as the first generation 707s and DC-8s, and more recently the turbofan was being introduced on the 707 – but now, new engine concepts involving more powerful and quieter high-bypass-ratio engines would have to be perfected. Turbofans generate much more thrust by passing large volumes of air through a fan at the front of the engine. The fan is driven by the core of the engine, and is basically similar to the original turbojet's core, but what was revolutionary was that a large amount of the fan-driven air 'bypassed' the core and went straight to the exhaust through an annular duct that enclosed the core. This results in greater thrust, while at the same time the bypass air wraps itself around the core, providing insulation to cushion the sound of the noisy jet blast. All in all, high-bypass-ratio engines produce a quieter, cleaner, more fuel-efficient and less smoky powerplant than the turbojet.

During the early 1960s Boeing stayed ahead of Douglas in the airline market by introducing short-haul and medium-range developments of the 707 series with models such as the 720 (165 seats), the 727-100 (70–114 seats) and the 737 (88–113 seats), while the 707 (189 seats) maintained its unassailable position in the global arena by courtesy of a programme of continual improvement. This resulted in even bigger and better versions – but there comes a point when an aircraft design, even one as good as the 707, can go no further due to its structure and engine thrust limitations. So it proved ultimately with the 707, the 707-320 intercontinental proving the last of the famous breed. Compared to the DC-8's tall main landing gear, the 707's gear was lower off the ground, so the potential to 'stretch' the overall 707 design to increase passenger volume was

immediately reduced. On the other hand, the Douglas airliner now enjoyed a decisive advantage over its more illustrious swept-wing rival because it was found that the DC-8-50 (117–173 seats) could be stretched more easily – by 36.9ft (11.2m) – and so the famous Super 60 series, capable of seating up to 251 passengers, was evolved almost effortlessly by comparison.

Restricted by limitations imposed by their model's shorter and stockier landing gear, Boeing struggled to make the figures work. At first they designed the 707-820 concept by 'stretching' the 707-320B by 40ft (14m) and using a bigger wing, which would produce a higher gross weight of up to 400,000lb (181,440kg), seating for 230 passengers, and a range of 5,000 miles (8,045km). On a smaller scale, the 707-620 concept, seating about 200 passengers, was studied. The -620 concept was a non-starter, but the -820 concept could work if a suitable turbofan could be found to power it. Rolls-Royce, with its 17,500lb- (7,938kg-) thrust Conway Mk.508, was the first engine manufacturer to produce a conventional commercial turbofan. Pratt & Whitney followed with their 18,000lb- (8,165kg-) thrust JT3D-3, while General Electric weighed in with the CJ-805, which in its initial form powered the Convair CV-880 four-engined airliner. The CJ-805-21 derivative, which was based on the J79 engine used to power the Convair B-58 Hustler supersonic bomber, and which produced more thrust when an 'aft fan' was introduced, was developed for the Convair CV-990.

While these turbofans produced enough thrust to power the DC-8-60 and Vickers VC-10 long-range airliners, they were not powerful enough for Boeing's stretched 707 concept airliners, and nowhere near powerful enough for the CX-HLS (later the C-5A Galaxy). (For this project, General Electric abandoned development on the CJ-105 and proceeded with the 41,000lb- (18,600kg-) thrust TF-39-1 two-shaft turbofan, which ultimately proved successful.) A 22,500lb- (10,200kg-) thrust commercial version of the Pratt & Whitney JT3D-15 turbofan, developed for the Lockheed C-141 Starlifter, at last provided Boeing with new options. It would permit Boeing to stretch the 707-320B by 46ft (14m) and so create the 707-820/505, and it allowed them to consider an even bigger version, the 820/506, which incredibly was 56ft (17m) longer than the -320B and could carry up to 279 passengers. However, if these designs were to proceed successfully, then the bigger wing and longer fuselage would, in turn, mean a complete redesign of the main landing gear and wing carry-through structure, while the tail would have to be extended upward as the ventral fin had to be deleted to avoid the danger of tail strikes. (By comparison, the more easily derived DC-8-61, with its simple stretch fuselage, could carry 251 economy class passengers, while the DC-8-62 and -62F, with nothing more dramatic than a shorter fuselage, 3ft (1m) wing-tip extensions, new engine pylons and redesigned long-duct engine pods, could carry up to 189 passengers.) Not surprisingly, therefore, Boeing ultimately conceded that their stretched 707 concepts were unrealistic, even though they would have offered seat-mile costs (what it costs to carry a filled seat one mile) 26 per cent lower than those enjoyed by the -320B.

Diversity from Adversity

With the prospect of ever more powerful turbofan engines brightening the horizon, the giants of the commercial aircraft industry could continue their studies of huge airlifters and airliners with a degree of confidence, at least as far as jet propulsion was concerned. This confidence did not, however, extend to all parts of the CX-HLS project, which was consuming millions of dollars in development costs as design teams wrestled with the myriad problems associated with such a new and radical design. At stake was a $250 million development contract, but aerodynamic and structural problems had first to be overcome, while fatigue and structure weight considerations had to be confronted. The original requirement specified by MATS (Military Air Transport Service, later Military Airlift Command, MAC) was for the huge airlifter to haul 125,000lb (56,700kg) for 8,000 miles (12,872km), and it had to be capable of operating at maximum weight from unpaved surfaces. A 'high flotation' landing gear with twenty-eight wheels solved the latter requirement but the original specification was never met. As it turned out, in some respects CX-HLS was to prove a role model for the Boeing 747, but in others its growth had to be carefully monitored and its growing pains avoided if price escalation was to be contained to acceptable limits.

By August 1965 Boeing, McDonnell Douglas and Lockheed were able to submit their final designs for the CX-HLS project. Although Boeing had estimated that the cost of developing and then building 115 C-5As (production models) would cost around $2,800 million, their bid was for $2,300 million, *$500 million lower*. McDonnell Douglas submitted a bid of $2,000 million, and Lockheed undercut both of them to win the contract with a bid of $1,900 million, $300 million below the Pentagon estimate. In October the Georgia company was selected prime contractor – but events were to make it almost a pyrrhic victory. Problems associated with the aircraft design, coupled with the attendant cost overrun, and inflation, conspired against the aircraft, and eventually production had to be reduced from 115 to eighty-one examples, equipping just four squadrons. Furthermore, operational service resulted in wing fatigue which ultimately required a complete rebuild of the wing and inner sections at a cost approaching $1,000 million. What benefits could Boeing derive from the failure to win the CX-HLS contract? Obviously they could make excellent use of the development potential gained during the abortive airlifter project, and if the company avoided the high cost overruns, there was no reason why an equally large airliner could not be successful.

Re-Enter Juan Trippe

Apart from anything else, the loss of the CX-HLS contract almost immediately strengthened Boeing's resolve, from chairman Bill Allen down, to start building huge new airliners (powered by high-bypass-ratio turbofans developed for the CX-HLS), especially since commercial carriers, led principally by Juan Trippe, chairman of the all-powerful Pan Am, were now 'threatening' to buy 'stretched' DC-8s which were still in the planning stage. Pan Am was seen as America's national carrier, so when Pan Am took a lead, the other carriers followed. When asked why Pan Am should order new jet airliners that were not yet off the drawing board, let alone tested, his answer was, in the light of his all-conquering pioneering spirit, predictable: 'We ordered big jets as soon and as quickly as we could; then asked our engineers and economists to prove that we had made the right decision.' He would adopt the same buccaneering business style when it came to buying Boeing's big jet airliner, the like of which had never been seen before.

The First Steps Towards the 'Everyman Airliner'

Joe Sutter, then Boeing chief engineer, who had worked on the 737, was recalled from vacation by Bill Allen to head the studies on the 747. Sutter reported to the vice-president of engineering, George Snyder, and was allowed to commandeer any particular engineers that he wanted; however, he was expected to keep many already in place. (About a hundred engineers had crossed over to join the 747 project when the CX-HLS project had foundered, while others went over to the SST programme.) Among those who joined the 747 project was Rowland 'Row' E. Brown, head of the configuration group. It was Brown's group who would be responsible for sizing the 747 according to its intended passenger and cargo load. Brown was made aware that the new aircraft was first and foremost a large capacity airliner, both in terms of passenger and cargo, but supersonic transport (SST) aircraft designs were influencing thinking at the highest levels in the airline and aircraft industry, and they led to a popular misconception that Boeing's new 'super-carrier' was but a 'stop-gap' until an anticipated 1,250 SSTs would take over the passenger routes by the late 1970s. When this happened, the 'super-carriers' would have to be converted for use as large freighters.

The Design Group therefore opted to design the new airliner as a cargo aircraft from the outset, making it 'big and wide', just like the C-5A Galaxy. It was not a view immediately shared by John Borger, Pan Am vice-president and chief engineer, who was a major influence on the final design of the 747 – among other things he wanted, and got, pod-mounted engines on a low wing – but ultimately it was the right one. In the final analysis, Borger and Boeing both recognized and agreed that speed and the attendant high cost of the SSTs could not hope to compete with the subsonic aircraft's lower operating costs, nor rival it in the mass transportation sector of the market.

When he arrived on the 747 project, Sutter was presented with something of a *fait accompli* for it seemed that the new airliner should have a double-decker fuselage (like two 707s stacked one above the other) with six-abreast seating. Indeed, a wooden mock-up and a brochure showing this arrangement were already being produced for the airlines, and scale models had been constructed in just this configuration. While it would be ideal for an aircraft carrying 1,000 passengers, to apply it to an aircraft carrying 500–600 seats would only result in a misproportioned airliner that was short and stubby with a huge wing. In turn this would create problems with cargo loading and the servicing of the aircraft. Above all, a double-deck arrangement would affect emergency evacuation procedures and the door arrangement: it would be a nightmare to get passengers out given the height (35–50ft/10.6–15m) of the upper deck from the ground.

Sutter disliked the double-deck design, and he was equally disdainful of the high-wing, mid-wing and low-wing versions of the design study. A mid-wing design would mean that the main spar would run through the middle of the passenger cabin, with all the attendant problems it caused, while the low-wing concept made the cabin look ungainly and top heavy. Another model revealed three engines instead of four, mounted in the empennage topped by a high T-tail, while yet another had the flight deck situated under the passenger cabin. Sutter completely disregarded the 'turkeys', as he called them, but the last-named model, which was soon dubbed the 'anteater', did have merit if the flight-deck was moved upwards out of the way. Milt Heineman, who had previously worked on the 737 airliner, was responsible for working out ways of evacuating 350–400 passengers by the ninety-second rule laid down by the FAA; he shared Sutter's dislike of the double-decker configuration.

At Pan Am meanwhile, Juan Trippe enthused at the prospect of a single airliner carrying up to 500 passengers (but about 350 as a more typical load in mixed-class configuration) and a load of cargo, cruising as high as 35,000ft (10,670m). (In mid-November 1965, Pan Am tabled its passenger- and cargo-carrying requirements. The cargo-carrying version had to be capable of transporting 160,000lb (72,576kg) 2,872 nautical miles – the distance between New York and London – at Mach 0.8.) Pan Am was sceptical of the 747's projected cruising speed and was not impressed with the range of 5,865 statute miles (9,437km), which they thought a little short, bearing in mind that Pan Am's yardstick route for range was New York – Rome, which was being flown by 707-320Bs. Trippe, however was more concerned with the delivery schedule and threw down the gauntlet to Boeing, insisting that any new airliner had to offer him a seat-mile cost some 30 per cent lower than the best achieved by the 707. It meant that the new 'super-carrier' had to be able to cruise at 100mph (160km/h) faster than the earlier airliner. The top men at Boeing were under no illusions either, knowing that if they proceeded with the 747 and their engineers and designers got the configuration wrong, the huge financial investment involved was such that there would not be a second chance to get it right: the company would simply go out of business and cease to exist. Thus the task which confronted Sutter and his colleagues in that summer of 1965, if Boeing was to build such a huge aircraft successfully, was phenomenal.

As in the early days of the evolution of the 707 a generation earlier, it was the cabin cross-section which ultimately decided the fate of the double-deck configuration and created the successful platform for the entire 747 project. The germ of an idea was sown by a new international standard for freight containers which decreed that although they could vary in length, to achieve commonality when carried by road, rail and ship, their cross-section should be no more than 8 × 8ft (2.4 × 2.4m). Row Brown, who had previously configured the fat body for the CX-HLS, took this into account and decided that if the 747 was to be used to carry cargo in the first instance, and become a freighter later in its career, it would be quite sensible to apply the same dimensions to lightweight containers used to carry air cargo. This then posed questions of how to load the containers into the cargo hold of an aircraft, and where to stow them. Brown arrived at an outline where first one, then two of the freight containers were placed side by side in the belly of the aircraft. This in turn determined the width of the cargo deck's floor. To finish, he drew a circle around the deck and the freight containers to create what was a very wide fuselage some 20ft (6m) across at the level of the passenger cabin – almost twice the width of a 707 – which was situated above the cargo deck.

Sutter was delighted because it not only removed the double-deck configuration from the 747 equation, it also allowed him to proceed with the basic outline of scaling up the 707 while at the same time utilizing Brown's wide-bodied approach. He could even discount the one serious drawback concerning the single-decker – that its structure required greater rigidity than the

Before Sutter's appointment to head the 747 project it seemed that the new airliner would have a double-decker fuselage with six-abreast seating. However, this layout would have affected emergency evacuation procedures – it would have been extremely difficult to get passengers out, given the height (35–50ft/10.6–15m) of the upper deck from the ground. A mid-wing design meant that the main spar would run through the middle of the passenger cabin with all the attendant problems it caused, while the low-wing concept made the cabin look ungainly and top-heavy. Another model revealed three engines instead of four, mounted in the empennage topped by a high T-tail, while yet another had the flight deck situated under the passenger cabin. Sutter completely disregarded the 'turkeys' as he called them. Boeing

double-decker and so increased the weight of the fuselage by as much as 12,000lb (5,450kg) – because the overall advantages of the former far outweighed all other considerations. All Sutter had to do now was to convince the doubters at Boeing and at Pan Am.

Ed Wells was won over by Brown's wide-bodied single-decker configuration, and at Pan Am, Borger was of the same opinion since the greater cargo capacity appealed to him. Gradually Trippe would also be convinced, swayed by Heinemann's persuasive arguments concerning payload, cabin layout and in particular safety, with the single-decker's two-aisle configuration uppermost. Two immediate problems for Sutter to resolve, however, were the question of the aircraft landing gear and the degree of wing sweep. The new aircraft was anticipated to weigh around 600,000lb (272,000kg), but it would still be expected to use existing runways at airports and so the weight borne by each wheel was critical. Sutter considered several different landing gear configurations, and dismissed the conventional two-legged layout because it would have been huge. Finally, after pondering the use of two wing-mounted legs and one central leg, he settled for a sixteen-wheel, four-main-truck landing gear, a configuration which would spread the 'footprint' and enable Boeing to use the same wheels, tyres and brakes used on the 707-320B. The layout found favour, especially with Ed Wells who generations before had designed the gear on the B-17 Flying Fortress.

Initially, wing size and structure appeared to pose few problems because of the experience gained on the C-54, although this was not the case later). While a straightforward wingspan of 200ft (60m) plus would permit economical operation and keep fuel-burn within acceptable limits, thus keeping the airlines happy, the span had to be as short as technologically possible to permit acceptable operation on the ground. Maximum use was therefore made of such high-lift features as highly developed triple-slotted trailing-edge flaps and full-span leading-edge Krueger flaps. Sutter and his colleagues also wrestled with the problem of wing sweep, which was critical if they were to obtain the performance that Boeing promised to deliver. More wing sweep made the wing more prone to yaw (side to side oscillation), and yaw in turn caused 'Dutch roll' – a roll from which there is little chance of recovery.

The 707's wing was swept back by 35 degrees and Sutter wanted to go to 40 degrees (which had worked in the wind-tunnel model of the B-52) of wing sweep on the 747. Finally a compromise between all the interested parties at Boeing decided on 37.5 degrees, which lessened the risk of instability but permitted the higher speed. There was then the problem of the size of the wing. Ed Wells decided that the original wing area of 5,200sq ft (483sq m) was not big enough: he wanted it made bigger to lift a stretched fuselage in the future, and so the 747's wing was enlarged to 5,500sq ft (511sq m). The wing-flap system and the sixteen-wheel, four-main-truck landing gear would allow the 747 to operate from runways normally used by 707s.

Engine Propulsion

All the major components were falling into place, but there was still the question of the engines to consider. At Pan Am, Trippe was in no doubt: right from the start he had wanted Gerhard Neumann's big General Electric 41,000lb- (18,600kg-) thrust TF-39 turbofan engine, designed for the C-5A. However, this engine was designed for the C-5A's lower cruising speed of Mach 0.78 and was therefore unsuitable for the 747. The GE engine had a very high bypass ratio (the amount of uncombusted cool air flowing round the hot engine core in relation to that passing through it) of 8:1. The early turbojets, like the de Havilland Ghost, four of which powered the Comet, were derivatives of military engines and had a bypass ratio of zero. (In a pure jet engine, air is drawn in at the intake in a steady stream; it is then compressed by a compressor, fed to a combustion chamber and heated by burning fuel, and then passed as white-hot gas through a turbine which drives the compressor. The gas is then expelled backwards at hundreds of feet per second through a nozzle to provide thrust. This efflux converts the engine's heat and pressure into kinetic energy, driving the aircraft forwards.)

Then came the turbofan, pioneered by Rolls-Royce chief engineer, Adrian Lombard, with bypass ratios ranging from 0.5 to 1.5. Turbofans with high bypass ratios leading to maximum thrust are the most powerful engines. (Their larger compressor blades bypass additional air around the engine core, simultaneously increasing thrust and reducing noise and fuel consumption.) The first Turbofan to enter service, in 1960, was the Rolls-Royce 17,500lb- (7,950kg-) thrust Conway Mk.508, powering the Boeing 707. Pratt & Whitney soon followed with their 18,000lb- (8,165kg-) thrust JT3D-3.

In deciding the architecture and configuration of any engine, designers have to consider the critical questions of engine drag, weight, noise and emissions. John Cundy, head of Rolls-Royce propulsion systems engineering in the 1990s, explains:

> A major task is to improve the engine's fuel-burn by improving its propulsive and thermal efficiencies. Simply, better propulsive efficiency means getting more useful power to propel the aircraft from a given amount of energy in the engine exhaust. Thermal efficiency is improved by increasing the engine's overall pressure ratio and turbine entry temperature, and using better, more advanced components. To get a higher propulsive efficiency you need lower waste energy in the engine's exhaust stream, which generally means lower jet velocity. Since thrust is the product of exhaust mass flow and velocity, if velocity has to be reduced then the mass flow needs to be increased to give a fixed level of thrust. This implies an increase in bypass ratio.

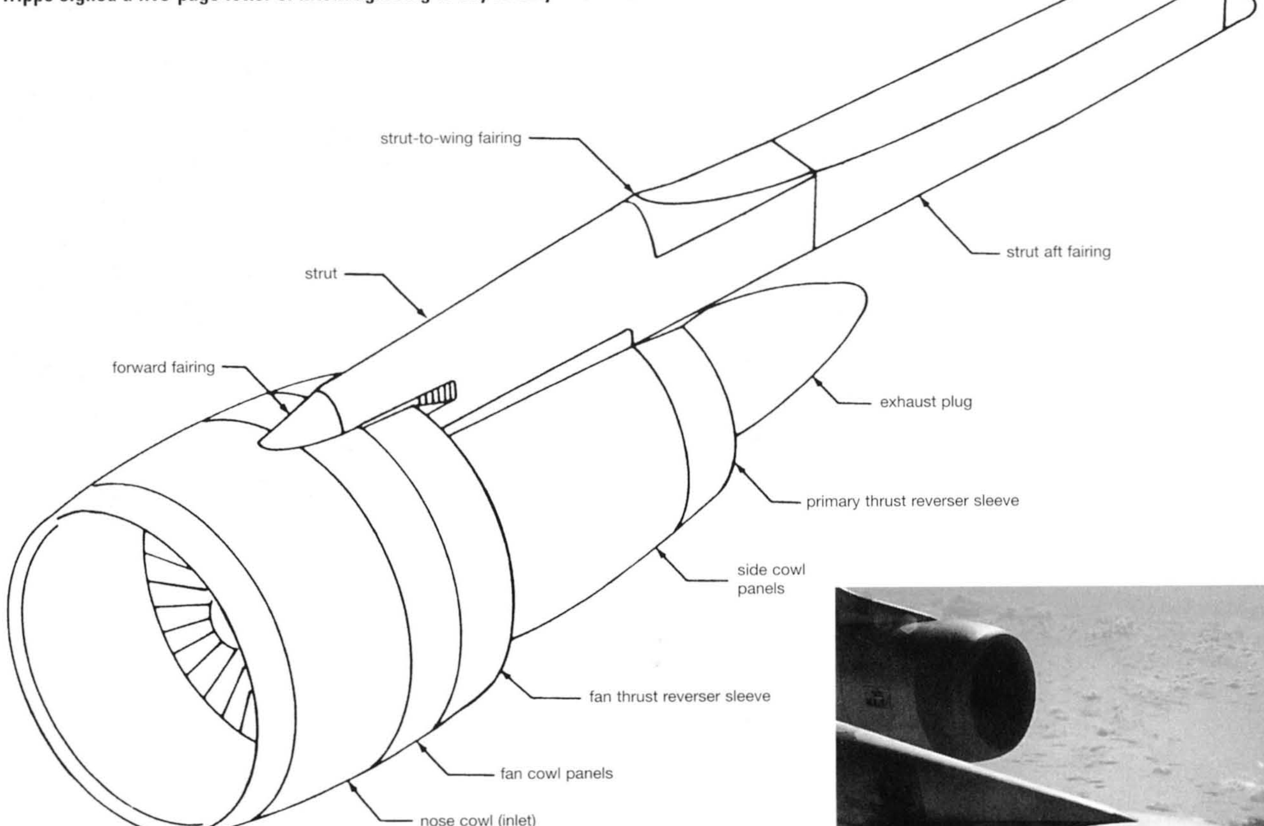
Pratt & Whitney were convinced that it could build a more flexible turbofan engine, better suited to commercial, operation than the proposed GE CF6 engine, with a ratio of 5½:1. The larger diameter fans associated with higher bypass ratios, such as the ones proposed by GE and P&W for the 747, bring both benefits and penalties (as will be seen). The bare engine would have lower specific fuel consumption, but the larger fan – Pratt & Whitney's projected JT9D engine would be characterized by an enormous front fan measuring 8ft (2.4m) in diameter – would require a large-diameter nacelle with consequent drag and weight penalties. In any event P&W, which at this time were responsible for 90 per cent of the world's jet engines, would virtually have the field to themselves. General Electric had their hands full trying to get their 41,000lb- (18,600kg-) thrust TF-39 engine to meet the performance requirements of the C-5A, let alone trying to use it to compete with the likes of Pratt & Whitney. (The resulting 51,000lb- (23,100kg-) thrust CF6-50 engine was later used to power the McDonnell Douglas DC-10. Boeing had, from the start of the 747 project, wanted to use the GE engine. After costing Boeing an

estimated $46 million for its certification, the CF6-50 was finally adopted for the 747-200B in 1972. The first 747 re-engined with the GE engine flew on 26 June 1973.)

Rolls-Royce, meanwhile, had staked the company's future on its RB.211 high-bypass-ratio engine (the 'R' is for 'Rolls' and the 'B' is for 'Barnoldswick', the town in Yorkshire where much of the engine work is completed). Ever innovative, Rolls had come up with an engine that promised much, but it was still too early in the design stage and considered too complicated in its construction to interest Boeing, and Joe Sutter in particular. The RB.211 was heavier than the GE and P&W engines – it was powered by three spools, or shafts, two more than the American engines – and Boeing was not impressed by the largest fan blades, called 'hyfil', which had a carbon-fibre core thinly coated with steel. Rolls claimed that these were lightweight but strong, and therefore offered substantial weight savings, but Boeing remained unconvinced. They no doubt felt vindicated some time later when the hyfil blades failed a vigorous engine field test after being bombarded by defrosted frozen chickens for forty hours!

Lockheed in turn bought the RB.211 to power its three-engined L-1011 airliner, later named TriStar, but after landing orders from four major US airlines for 172 TriStars, the aircraft proved to be another highly expensive enterprise for the California company. Rolls-Royce Aero Engines went bankrupt trying to produce the RB.211 engine on an accelerated schedule, and in 1971 were placed in the hands of the receivers. Production of TriStars ceased immediately. Without government help, the Lockheed Aircraft Corporation would have followed the British engine manufacturer into bankruptcy. As it was, Lockheed sold 244 TriStars, fewer than half the number they needed to break even, and the company lost an estimated $2.5 billion on the L-1011 project as a result.

At Pan Am, Juan Trippe wanted General Electric's 41,000lb- (18,600kg-) thrust TF-39 turbofan engine (designed for the C-5A) to power the 747, but Boeing decided upon the Pratt & Whitney JTD9. No engines had been chosen when, on 22 December 1965, Juan Trippe signed a five-page letter of intent agreeing to buy twenty-five 747s.



(Right) **General Electric were so committed to perfecting their 41,000lb- (18,600kg-) thrust TF-39 engine to meet the performance requirements of the C-5A, they were unable to compete with Pratt & Whitney to provide the winning engine for the 747. However, from the start of the 747 project Boeing had wanted to use the GE engine, and the CF6-50 was finally adopted for the 747-200B in 1972. The first 747 – re-engined with the 51,000lb- (23,100kg-) thrust CF6-50D – flew on 26 June 1973. KLM was the first airline to use GE CF6-50 engines (the 52,500lb- (23,800kg-) thrust -50E) on its 747-200s, and the military F103-GE-100 version of the -50E also powered the USAF's E-4s.** Author

Rolls-Royce, which had pioneered the turbofan engine, lost out to Pratt & Whitney for a suitable engine to power the 747-100 when Boeing decided that its RB.211 was too complicated in its construction to interest them. A more powerful version appeared in 1973, and the 53,000lb- (24,000kg-) thrust RB.211-524 was finally fitted to the 747 when British Airways ordered its first four -524-engined 747-236Bs in June 1975. The first RB.211-powered 747-236B flew in 1976, and deliveries to British Airways began in 1977. Rolls-Royce

An all-new Rolls-Royce company went on to produce the RB.211 after convincing the British government of the day to fund half the development of the more powerful -524 version of the engine. In 1973 the first static test runs were made, but it was not until mid-1975 when the British government at last provided the additional funding Rolls needed that the company could turn the 50,000lb- (22,680kg-) thrust RB.211 into a production quality engine, and further develop its full potential to 53,000lb (24,000kg) of thrust. RB.211 engines (without the troubled hyfil blades) were finally fitted to the 747 when British Airways ordered its first four -524-engined 747-236Bs in June 1975. The first RB.211-powered 747-236B flew in 1976, and deliveries to British Airways began in 1977.

A Letter of Intent

The selection of the engine to power the 747 was due to be made by Boeing and Pan Am on 3 January 1966, but by the end of 1965 this looked untenable since no final design of the 747 had been arrived at, and no engines chosen. Even so, on 22 December 1965, Juan Trippe signed a five-page letter of intent agreeing to buy twenty-five 747s, although this was only after first receiving a guarantee from Boeing that Pan Am would receive the first five aircraft built, and then five of each of the first three batches of ten, and five of the next fifteen off the production line. Trippe obviously wanted to make the 747 market Pan Am's own for as long as

possible in order to steal a march on his rivals; however, Boeing needed to sell at least fifty 747s just to recover its pre-production costs.

The aircraft was newly developed, untested, and without engines, and an entirely new aircraft plant would have to be built before production could begin. So in view of the enormous financial investment that Boeing was risking, the aircraft company stipulated that Pan Am pay a 2.5 per cent deposit on signature of the contract, then put up half the total price of each of the aircraft, paid in quarterly amounts, six months prior to delivery of the first 747. Each of twenty-five 747s would cost Pan Am $18 million – a $450 million investment – and the terms of the contract meant that the airline was paying a quarter of a billion dollars before the first aircraft flew. However, the future seemed rosy. In 1965, which had proved very profitable for Pan Am, it had been forecast that 35 million people would be flying the intercontinental routes, and forecasters were predicting a 200 per cent increase by 1980.

At Renton on 4 January 1966 Boeing showed the six Pan Am representatives – General Larry S. Kuter, Sanford Kauffman, John Borger, test pilot Scott Flower, and two senior captains – their designs for the seven final configurations. Four were single-deck designs (including one which was a fall-back, mid-wing, 'double-bubble' layout) with seating for eight, nine or ten abreast. (Sutter ultimately decided upon a low, swept-wing arrangement.) The other three were double-deck designs with a mid- or high wing. The double-deck designs had seating for six abreast on each deck in one configuration, seven in another, and a third with seating for seven abreast on the top deck and eight across on the main deck. Pan Am's representatives could not fail to notice that the upper deck was more than 25ft (7.5m) above the ground. This was brought home to them during their inspection of the mock-up where they had to make their way up to the upper deck by climbing unstable ladders, a tortuous and precarious route. By comparison, the drawing of the passenger deck on the widebody configuration showed it to be a more manageable 16ft (5m) from the ground, the cabin contained nine seats across, and it had been given two aisles to make it easier for passengers to get to the exit doors in the event of an emergency.

John Borger in particular could not help but be impressed by the fact that in all of the single-deck designs, unlike the double-deck designs, there was room in the cavernous cargo hold for not one, but two 8 × 8ft (2.4 × 2.4m) containers. So that it could be used more effectively in a freighter role, Borger had argued repeatedly for the main deck to have a hinged nose section to permit straight-through cargo loading. Sutter's problem then had been to calculate where the flight deck was to go, and ultimately he had moved the cockpit up and out of the way onto a small upper deck section, well above the 18ft (5.4m) high ceiling of the forward cabin, and more than 30ft (9m) off the ground. This was to give the aircraft its distinctive 'hump', which became a classic feature of the 747 design. (The 747 was the only jet aircraft with passengers seated ahead of the pilots.) The top of the raised flight deck projected well above the top line of the fuselage, but rather than fairing it into the fuselage abruptly, the fairing was made long, and formed the ceiling of an entire cabin.

The outcome of the single- versus double-decker configuration was still in the balance, but it was finally resolved in March 1966 when Trippe flew to Renton to view the plywood mock-up of the double-decker. First Bill Allen showed Trippe the lofty double-decker mock-up, and then the single-decker, with all its innovative features such as the upward-opening nose door and the hump behind the flight deck, which Borger suggested could be used as a rest area for the crew. The Pan Am chief was having none of that, however, quickly realizing its revenue-earning potential and marking it out for passenger use – why, it could be used as a cocktail lounge. This in turn created the problem of providing access to the upper deck. Straight stairs with two right-angled turns appeared too cumbersome and consumed too much space, so the spiral staircase as had been used on the old Stratocruiser, made a successful reappearance; indeed, it became one of the 747's famous features. (Some airlines later used the upper deck cabin for a crew rest area or a first-class lounge, while others fitted seats and windows for nineteen passengers. As this feature gained in popularity, the cabin was progressively extended aft to accommodate as many as ninety-nine passengers.)

Trippe even went so far as to consider putting a few staterooms on the upper deck, and asked if windows could be added to the front of the aircraft at the main-deck level (earmarked for the radar housing) so that passengers could see where they were going! All of this – and the fact that Boeing had deliberately placed a set of rickety steps up to the double-decker, but much firmer steps up to the nose section of the widebody, thereby showing their preference for the latter design – carried the day, and the single-deck arrangement was adopted as the winning design.

Despite the enormity of the project – no fewer than 75,000 engineering drawings would be used to produce the first 747, and more than 15,000 hours of wind-tunnel testing in eight locations in the US would be needed before the aircraft would fly – Boeing's designers did not envisage any dramatic technological problems. They had long experience behind them and more gained in the CX programme, and in the final analysis, on paper at least, the new 'super carrier' was really an enlarged and more powerful 707 – some 2½ times bigger, in fact – with a wingspan only 53ft (16m) greater than the 707-300 and a fuselage 79ft (24m) longer. Everything about the 747 would be on a large scale: it would have six million parts, of which three million were fasteners, about half of these being rivets. It would have 4.5 million moveable parts, with 135 miles (217km) of electrical wiring. The 747's 195ft 8in (59.2m) wide wings were designed to move up and down 29ft (9m) at the wing-tips to produce the flexibility needed to handle the effects of air turbulence on its vast 5,600sq ft (524.9sq m) wing area. The 747-100 would weigh 376,000lb (170,550kg) more than the 707-300, the weight increase being due mainly to the wide body cabin which would accommodate between 363 and 490 passengers (more than 200 additional passengers as compared to the 707), or 125 tons of cargo. It was expected to cruise at Mach 0.84, or around 650mph (1,046km/h), faster than the Boeing B-52 Stratofortress. The first 747's design range was 5,290 miles (8,510km).

Although the 747 was considerably bigger than the 707, the flight deck was roughly the same size due largely to the area-ruled design of the canopy shape and the windshield, which was curved for considerations of lower drag and noise. Generally, the instrumentation (there were 971 lights, gauges and switches) differed little from previous airliners. It

At the Renton plant on 4 January 1966, Boeing showed Pan Am representatives their designs for the seven final 747 configurations. It was here that the airline executives saw the mock-up of the 747 double-decker for the first time. The outcome of the single- versus double-decker configuration was still in the balance, but it was finally resolved in March 1966 when Juan Trippe flew to Renton to view the mock-up of the double-decker, and the recently completed nose section of the single-decker. Much to the satisfaction of almost all concerned, Sutter included, the single-decker configuration won the day. Boeing

had ADF (automatic direction finding), LORAN (long range navigation) and VOR/DME (distance measuring equipment) receivers. Boeing introduced the automatic flight control system (AFCS) which integrated several functions, including dual autopilot and flight-director systems (AP/FD), a dual-channel yaw damper (or stability augmentation system), and an autothrottle. At the heart of the innovative new system were three Sperry (later Honeywell) AP/FD computers.

The 747 was the first commercial aircraft to have an inertial navigation system (INS) fitted as standard from the outset. INS was a recent innovation in the 1960s. Originally it had been developed for use aboard US nuclear submarines and for the Apollo space programme, and basically it allows point-to-point navigation without the need for ground-based aids, and comprises a horizontally stabilized platform, a computer, a mode selector, battery, and a control and display unit. The 747 boasted three independent INSs, each one providing a primary reference for the LORAN and for attitude control. This remarkable piece of equipment takes into consideration every factor affecting navigation, including ground speed wind velocity, track angle and

Juan Tripple at Pan Am decided that the upper deck on the 747-100 would be used for passengers and not as a crew rest area. This in turn created the problem of providing access to the upper deck. Straight stairs and one with an intermediate right-angled turn appeared too cumbersome and took up too much space, so the spiral staircase, which had been used on the Stratocruiser, made a successful reappearance – it became one of the 747's famous features. Eventually the straight stair was adopted and used on all successive models of the 747. Boeing

The 747 flight deck was roughly the same size as that of the 707, due largely to the area-ruled design of the canopy shape and the windshield, which was curved for lower drag and noise considerations. Generally, the instrumentation differed little from previous airliners, although the 747 was the first commercial aircraft to have an inertial navigation system (INS) fitted as standard from the outset. Altogether 971 lights, gauges and switches are used on the 747-100 (and the SP, pictured) instrument fit – a far cry from the 'glass' flight deck of today. Boeing

also drift, and it presents the flight crew with highly accurate display information, including constant latitude and longitude readout and miles to waypoint.

A design of the magnitude and sheer size of the 747 would change entirely the shape of air travel, crew complement (the normal flight crew is three, with up to thirty-three cabin attendants) and training, and equally pointedly, it would require a whole new infrastructure at airports, affecting as it did runway and taxi areas, and hangarage space, to name just a few important considerations. A 747 placed added demands on a whole host of services, from food and fuel replenishment, luggage capacity (85,000lb or 38,500kg of baggage) to engineering and spares stockholding, because they not only require more wheels and tyres and more subsystems, they simply require more of everything! (Pan Am's terminal at Kennedy International Airport in New York had to be rebuilt in 1968 to take the fleet of 747s at a cost of $216 million, and a new maintenance facility at the same airport cost another $98 million.)

Thus Boeing were not just simply designing a new aircraft: they were inventing an entirely new culture, one in which airports would be expected to adapt to meet the needs of the plane, and not the other way around.

CHAPTER TWO

The Dream Becomes Reality

On 12 April 1966 in the boardroom on the fifty-second floor of the Pan Am building in New York, Trippe explained to his board that each 747 would replace 2½ 707s, and would operate at 30 per cent less seat-mile cost. The 747 would take twenty-five minutes off each transatlantic crossing, and that traffic was expected to increase by at least 15 per cent a year into the 1970s. The board voted to approve the purchase of twenty-five 747s at a cost of $18,767,000 each, with an option for ten more. (With spare parts and other extras, this amounted to an outlay of $550 million, the biggest commercial purchase in the history of aviation.) On the same day, Bill Gwinn, at the head of Pratt & Whitney, announced his company's intention to develop the 41,000lb- (18,600kg-) thrust JT-9D fan-jet engine (which had lost out to the GE engine in the C-5A competition) to power the huge aircraft, which, if all went according to plan, would allow Boeing to retain the four-engine configuration of the 707. It would be the most powerful aircraft engine ever built – just one of the powerplants was capable of producing more thrust than all four engines combined on the first Boeing 707s.

The Model 747's existence was made public two days later, when the details of the Pan American order for twenty-five aircraft, with deliveries to begin in 1969, was announced. The effect on the press and public alike was as awesome as the aircraft itself. Truly monumental in size, the fuselage would be 225ft (68.6m) long, the tail as tall as a six-storey building. Pressurized, it would carry a ton of air. The cargo hold would have room for 3,400 pieces of baggage and could be unloaded in seven minutes. The total wing area would be 5,500 sq ft (510 sq m). Yet the entire global navigation system weighed less than a modern laptop computer. Much to Boeing's chagrin, the press quickly dubbed the huge new airliner the 'Jumbo Jet'.

Pan Am's order was contingent upon other airlines placing enough orders by a certain time to make production of the new model practical. However, Boeing were so confident of the market potential for the 747 that in June 1966 the company took up an option on 773 acres (313 hectares) of land adjoining Paine Field near Everett, Washington, 30 miles (48km) north of Seattle, before the required number of orders was in hand. (Lufthansa and JAL each ordered three 747-100s on 25 July 1966, and in May 1967 United Airlines ordered thirteen 747s.) Built at a cost of $200 million, the plant, alongside a new 9,900ft (3,018m) runway, was planned around the one main assembly building. The single roof, reaching to a height of ten storeys, would span 63 acres (25.5 hectares) and contain the largest volume of any building in the world, some 205 million cubic feet (5,805,293cu m) 70 million cubic feet (1,982,295cu m) more than the Vertical Assembly Building at the Kennedy Space Centre, previously the world's largest building. (In 1980, the main assembly building was enlarged to 291 million cubic feet (8,240,684cu m) to further accommodate Boeing 767 production, and today, major parts of the 747 and 767 manufacturing subassembly and final assembly functions are all housed under one roof.)

When construction work began, interminable rains which continued for sixty-seven days caused mudslides that cost $5 million to clear. In July 1966 a 747 product development group was established at Everett with Malcolm T. Stamper at its head; Stamper was a corporate vice-president, responsible for the design, development, manufacture, delivery and support of the 747. Early in 1966 he set 17 December 1968, the anniversary of the Wright brothers' first manned flight, as the target date for the inaugural 747 flight. Two low-bay manufacturing sites, and a primary and a 300 × 300ft (91 × 91m) subassembly area, were the first new buildings to be built on the new site. Next came the three main 300 × 1,000ft (91 × 305m) assembly bays where production of the 747s would begin. In November 1966, large roof structural beams were lowered into place on the first of the major final assembly line buildings. Finally, the first production employees were in the new factory complex by early 1967, and production of the first 747s began as final phases of the factory building project were completed.

By May 1967 most of the major tooling was installed, and the first significant pieces of the airframe were beginning to take shape. The early use of numerical controlled (NC) machines costing $3 million each, was made, and this succeeded in reducing the number of physical gauges needed. NC-produced simulated break-rings were used to make all the interface controls between fuselage sections, and they also served as dimensional controls as well as shipping and fitting fixtures at Everett and at outside contractors' plants. By April 1968 the massive assembly tools needed to join the 747 body sections, and for the fuselage joining process itself, were ready. In May that year the equally huge production jigs for the wing assembly, and the fuselage joining fixture, were ready for work. Boeing-Wichita designed and manufactured an assembly jig for the nose section, and this was assembled at Everett. Much of the subassembly tooling was undertaken by the many subcontractors, and Boeing established a tooling action centre to monitor the 48,000 tools used. All told, the 747 production programme needed the design and fabrication of 270,000 tools with 182,000 – or 67 per cent – of these produced by outside contractors, and 88,000 – or 33 per cent – produced by the Boeing Company itself.

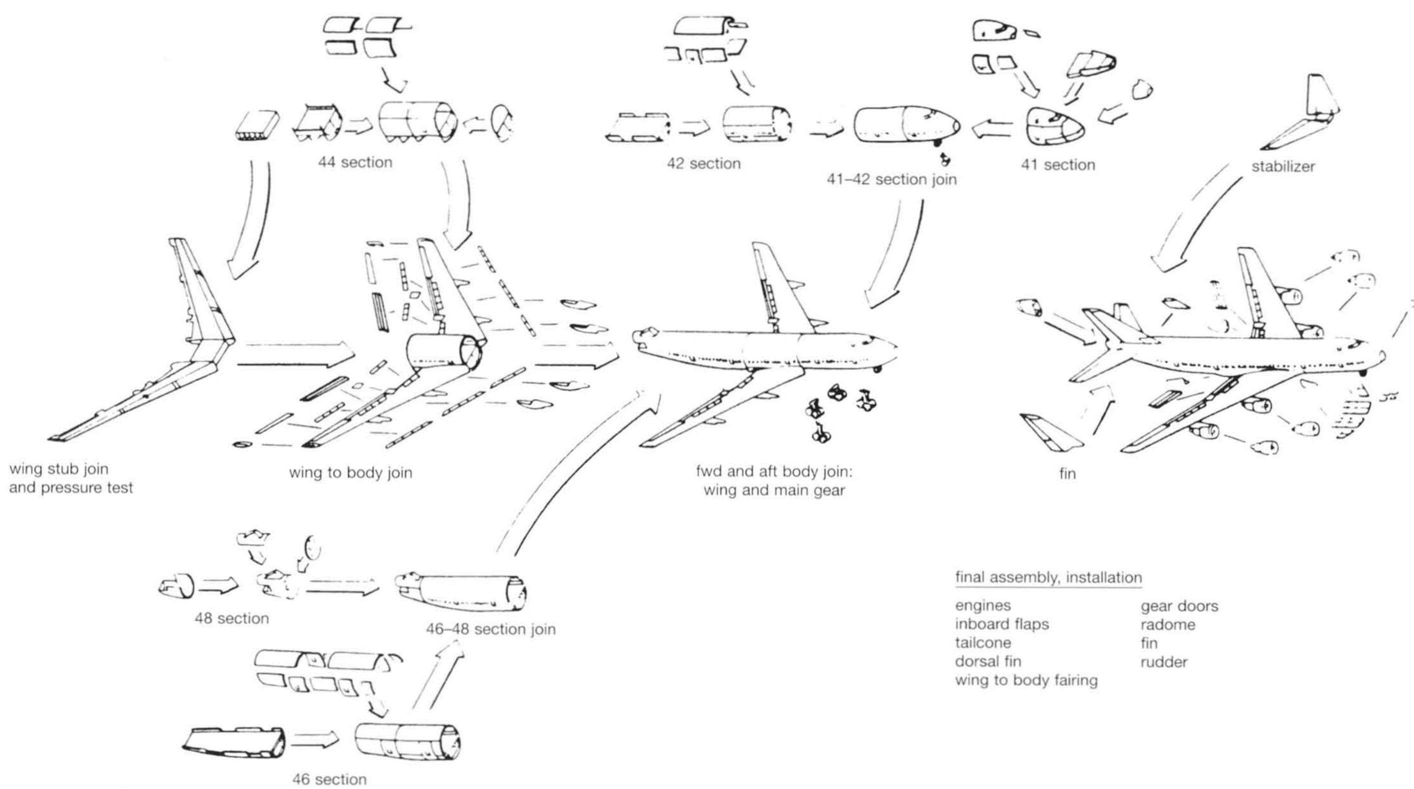
By August 1967 the first of the all-important subcontract parts began to arrive at Everett from all over America and beyond. (To get parts into the plant, and the 34,000 tons of structural steel to build it, a railway spur with the second steepest gradient in the US had to be constructed.) It was a massive undertaking, with Everett the final destination for thousands of subassemblies from 1,500 prime suppliers and as many as 15,000 secondary suppliers, all scattered across the US and eight other countries. The forty subassembly panels for the rear fuselage were

All told, the 747 production programme needed the design and fabrication of 270,000 tools with 182,000 (or 67 per cent) of these produced by outside contractors, and 88,000 (or 33 per cent) produced by the Boeing Company itself. By August 1967 the first of the all-important subcontract parts began to arrive at Everett from all over America and beyond. Thousands of subassemblies were provided by 1,500 prime suppliers and as many as 15,000 secondary suppliers, all scattered across the US and eight other countries. In this series of photos the section comprising a 747-100's nose (manufactured by the Rohr Corporation) and forward fuselage (section 42, manufactured by Grumman, and later by Northrop-Norair) is hoisted across the shop floor to be mated with the wing/aft body join (section 44), and the tail-end section 48; multi-bolt flange joints and fish plates were used for this. Main and wing gear and section 42 are all added, and the fin and stabilizer are hoisted into position atop the aft body. Boeing

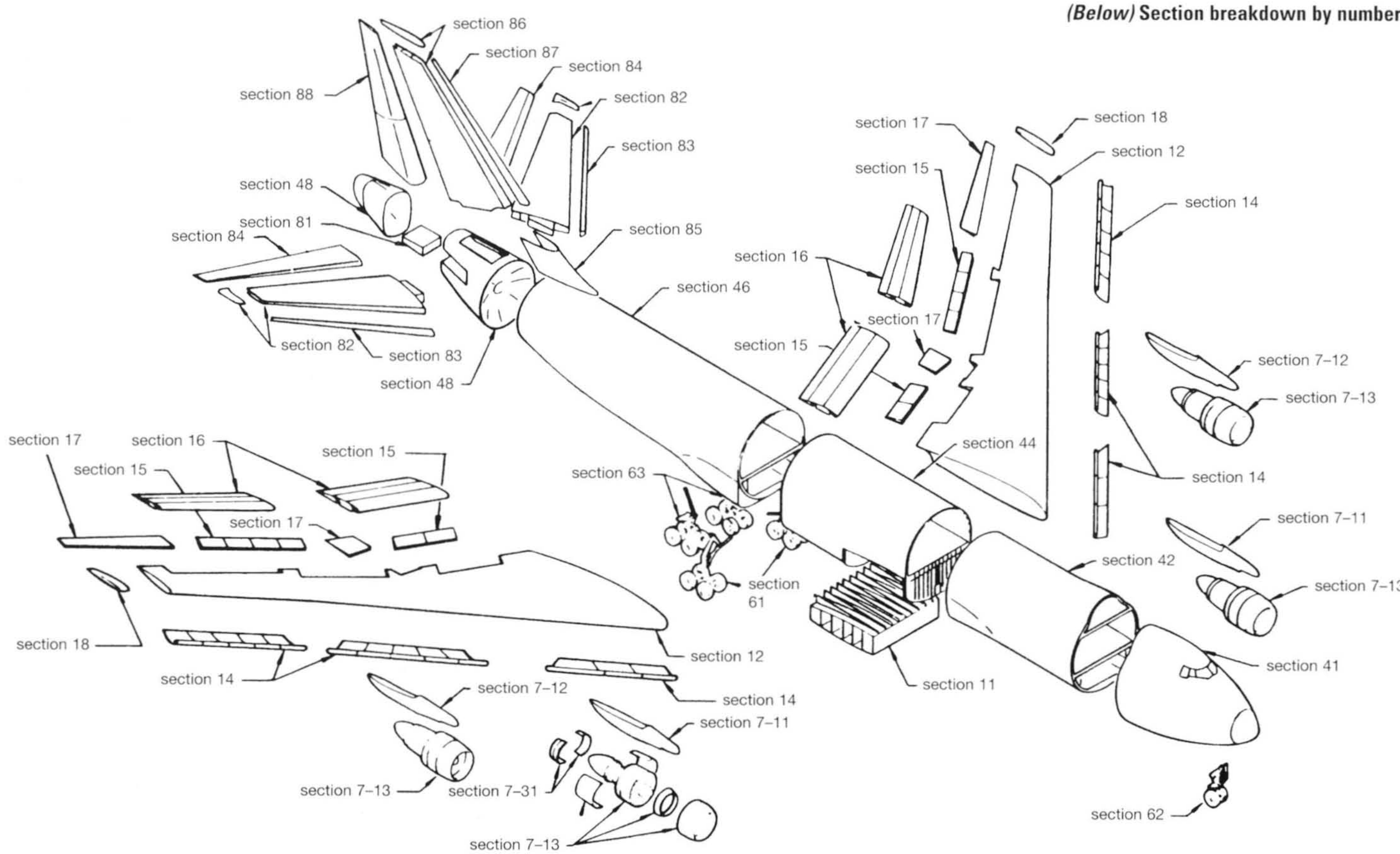
built by Northrop's Norair Division in Hawthorne near Los Angeles international airport. The composite fibreglass/light alloy leading edge of the wing was manufactured by North American, while Fairchild Hiller built all the leading- and trailing-edge flaps and controls, which were constructed largely of honeycomb skins with light alloy frames, ribs and spars. The 105ft- (32m-) long wing main spars were produced at a specially built plant of 4 million square feet (371,600sq m), on a 260 acre (105 hectare) site in Auburn, 20 miles (32km) to the south of Seattle at a cost of $150 million. Wing skin panels were produced at the Auburn plant, and in September 1967 wing construction began at Everett with the sophisticated Drivematic wing skin/stringer riveting machine being 'loaded' for the first time. Spars and stringers were joined to the skin panels using approximately 52,000 rivets in each wing set.

Boeing's 747 employees did such an incredible job, working for the first part in a plant without heat and a roof, that they actually became known as the 'incredibles', and T-shirts, hard hats and mugs were inscribed with this logo printed on them. The construction of the main assembly area was completed late in 1967,

Manufacturing sequence.



(Below) **Section breakdown by number.**



(Above) **747 wing to body join assembly at Seattle.** Boeing

747-100 N7470 41–42 section under construction. Mounted on the forward pressure bulkhead will be the radome, the weather radar and the localizer aerials for the instrument landing system. Boeing

Sutter pondered several different landing gear configurations. After considering the use of two wing-mounted legs and one central leg, he finally settled for a sixteen-wheel, four-main-truck landing gear, a configuration which would spread the 'footprint' and enable Boeing to use the same wheels, tyres and brakes used on the 707-320B. To save weight, body-gear steering was not installed at first, and steering on taxiways and runways therefore had to be made using engine power for turns. This soon changed, however, after the early test flights, when the 747 blew into the mud a station wagon full of people watching from the side of the runway. An electro-hydraulic system slaved to the nose-wheel steering was installed, at a cost of $5 million for redesign and tooling! In keeping with the 747's planned multiple redundancy, in emergency, the main landing-gear strut was given its own extension system that electrically unlocks the gear and the wheel-well doors to allow the gear to 'fall out' and lock in the 'down' position. via Mike Rondot

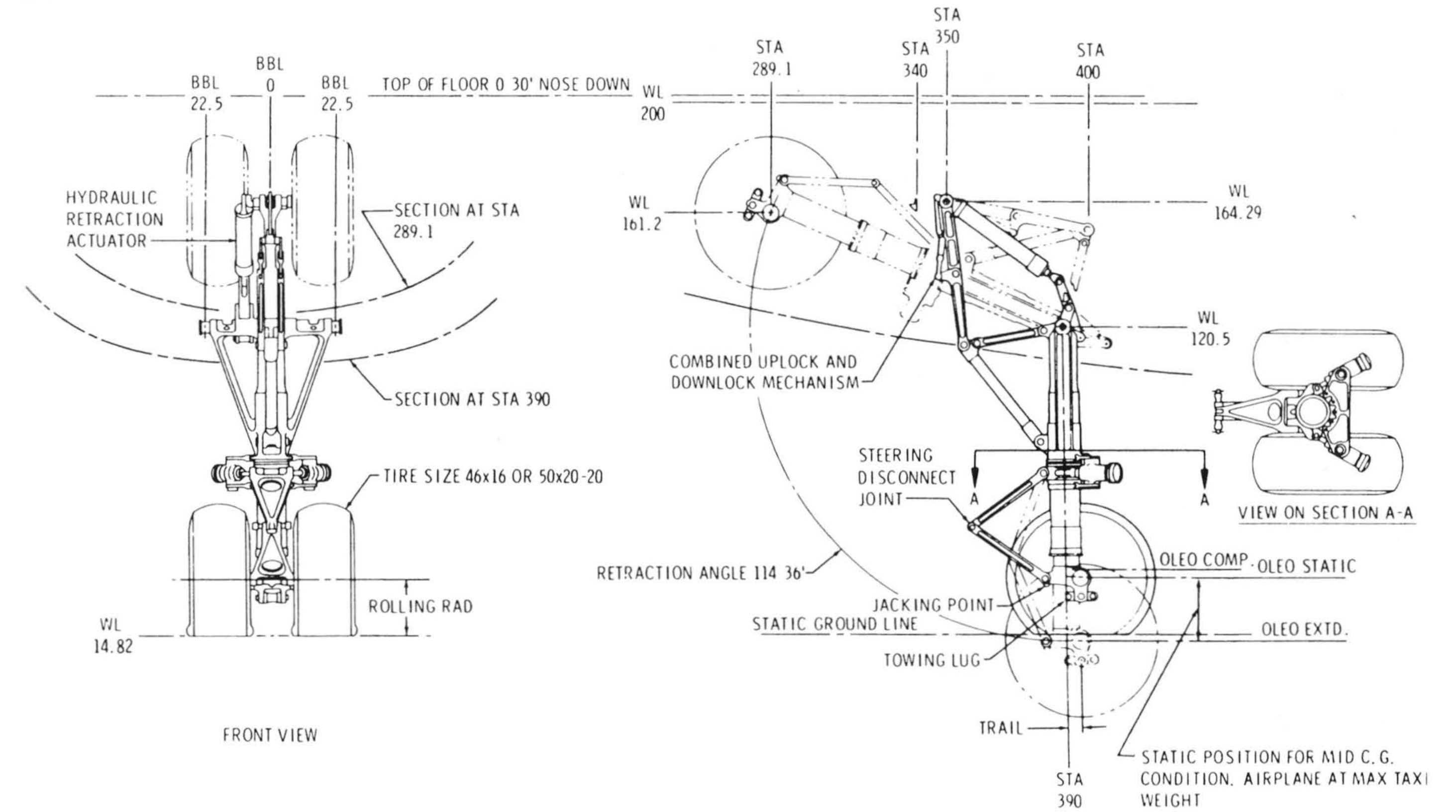
and the first workers were on site by December. Ultimately, 6,000 engineers would be needed to design more than four million independent parts.

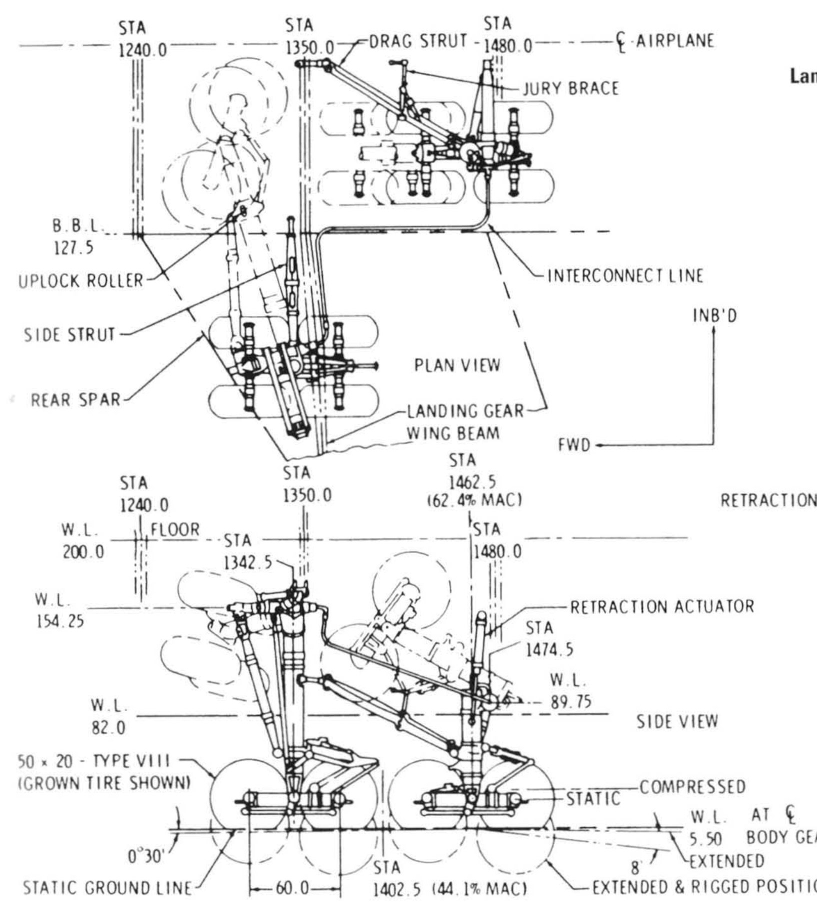
No jet airliner had ever been developed in such a short time, either before or since, and only about six months had been spent on preliminary design. Although a 747 mock-up was built, in building 40.53, one of the two low-bay sites, there was not even the luxury of a prototype. Now that the aircraft entered a more detailed design phase almost immediately, the delivery schedule began to slip because of the need for additional, unforeseen design studies (for instance, the nose had to be completely redesigned, at a great cost, to improve airflow around the frontal area), and the aircraft weight also began to rise at almost every turn. By mid-1967 the gross weight of the 747 was threatening to undermine the whole programme. Much of the increase in weight was caused by additions and changes requested by Pan Am.

The 747 had been designed to a maximum take-off weight of 680,000lb (308,448kg) but very soon it had grown to 710,000lb (322,056kg). In early June the 747 was expected to exceed the 2 per cent weight variance allowed in the contract, or by as much as 10 tons. (Every 1,000lb (464kg) over the contracted weight would cost Pan Am $5,000 per aircraft a year in lost payloads.) Also, the weight situation meant that whereas the P&W JT9D originally needed to produce 41,000lb (18,600kg) of thrust for a take-off weight of 690,000lb (312,984kg), the same engine somehow had to now produce an extra 1,000lb (464kg) of thrust to get 710,000lb (322,056kg) of aircraft into the air.

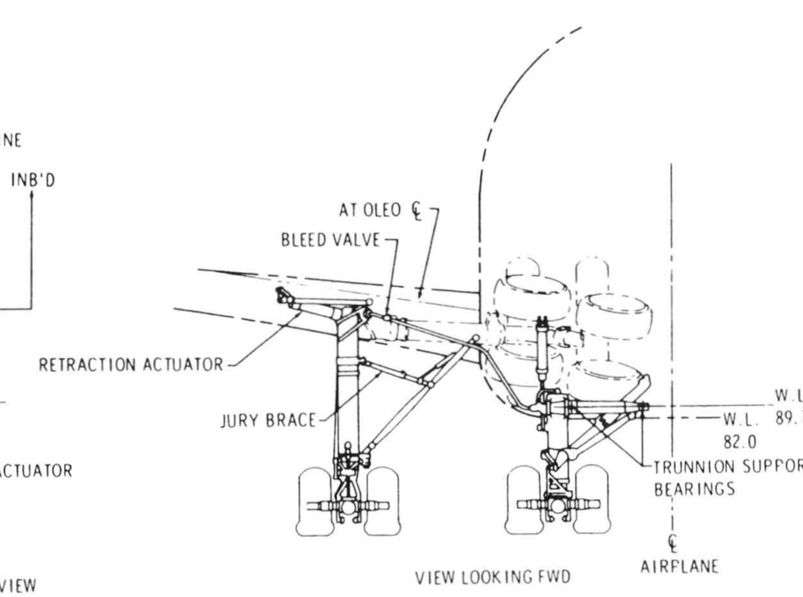
An early attempt to lose some of the excess weight was suggested by converting the triple-slotted flaps to double-slotted flaps, thereby saving 1,700lb (770kg) at a stroke. However, this would affect the 747's stalling, approach and landing speeds, and anyway, the triple-slatted flaps were one way of countering any doubts raised about the 747's ability to land as easily as smaller jets (they helped reduce the stalling speed to 130mph (209km/h), so they were left as they were. Another way of avoiding weight was not to fit body-gear steering, which saved about 500lb (227kg). (Steering on taxiways and runways therefore had to be made using engine power and nose-wheel gear for turns.) However, it would soon become obvious (starting with the test flights, when the 747 blew a station wagon full of observers by the side of the runway into the mud), that body gear steering would have to be fitted. This involved installing an electro-hydraulic system slaved to the nose-wheel steering which was operable at nose-wheel angles over 20 degrees. So, what was originally a weight-saving measure, finally finished up as a $5 million bill for redesigning and tooling. While some of the weight increase could be lost without penalty, it was obvious very early on that to still meet the performance specification, the P&W engine would have to produce more thrust. After much wrangling on all sides, Pratt & Whitney finally agreed to build a more powerful JT9D engine, and to absorb the additional $350 million cost themselves.

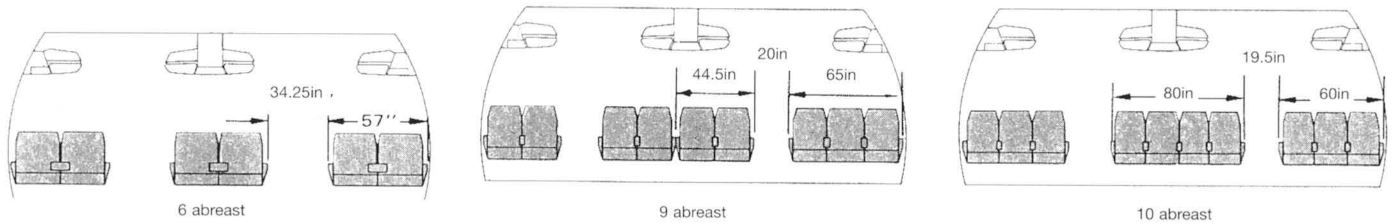
Landing gear – nose arrangement.



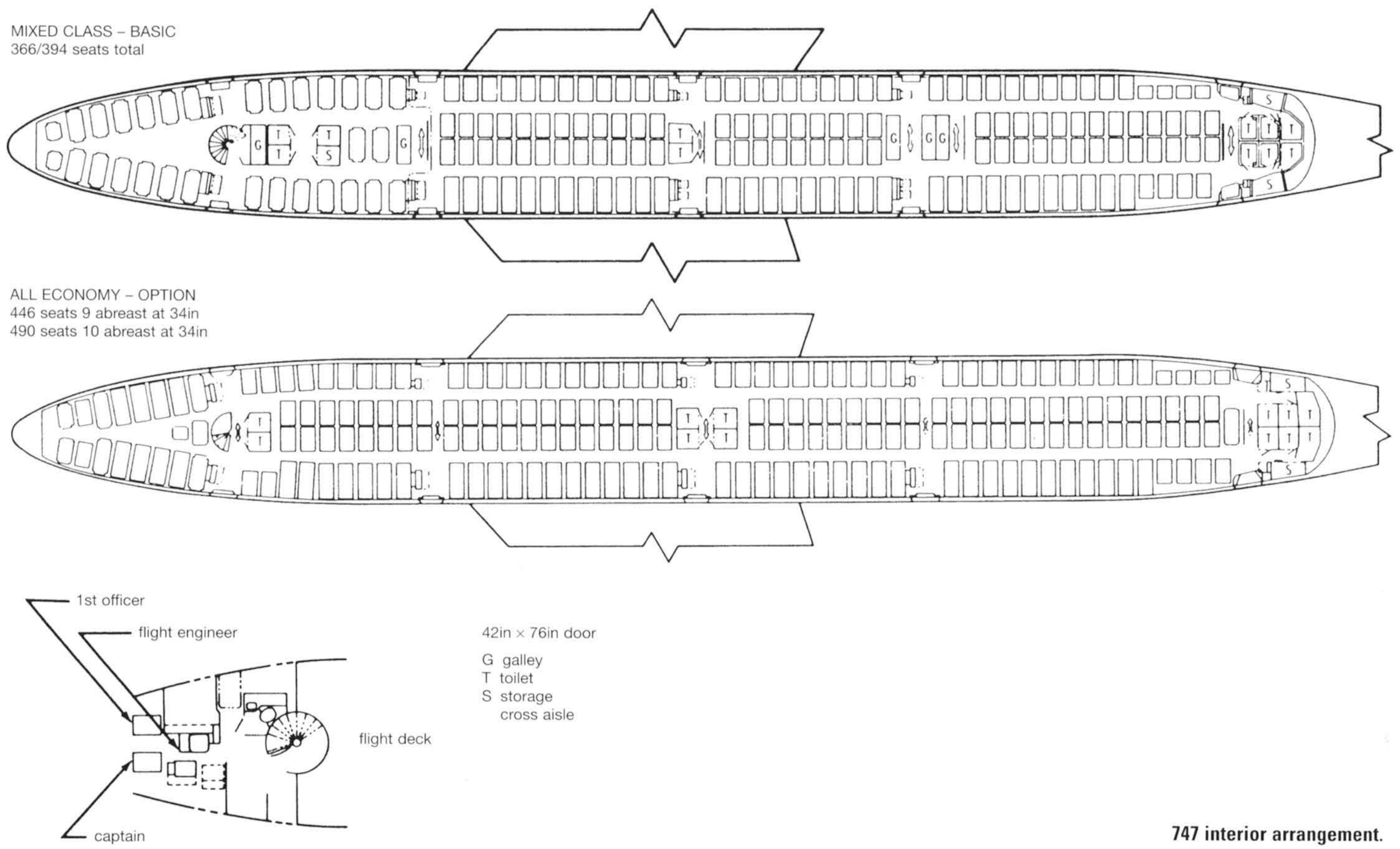


Landing gear – main arrangement.





747 cross-section.



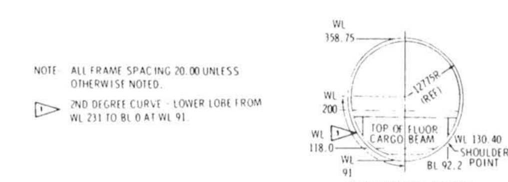
747 interior arrangement.

Another serious problem, namely emergency evacuation, manifested itself early in the programme. Larger aircraft mean longer boarding times, slower turn-around times (the enormous capacity of the 747 required significant changes in normal loading and unloading techniques), and they require more entry, exit and evacuation doors (the passenger version was the first jetliner to offer double-width passenger entry doors – five on each side of the fuselage – and dual fore and aft aisles to ease passenger traffic congestion both in flight and on the ground). To accommodate them, the main deck had to be divided into compartments for varying passenger arrangements, with seating up to ten abreast in the high-density seating versions. Unfortunately the first evacuation tests, in which every single passenger had to be able to evacuate the aircraft in ninety seconds, went disastrously wrong. Volunteers of all ages, who were paid a small fee for the tests, had to slide down chutes attached to the doors on the main deck from a height of 16ft (5m), and from a height of 30ft (9m) in the case of the upper deck. Several people were injured, some suffering broken bones or friction burns.

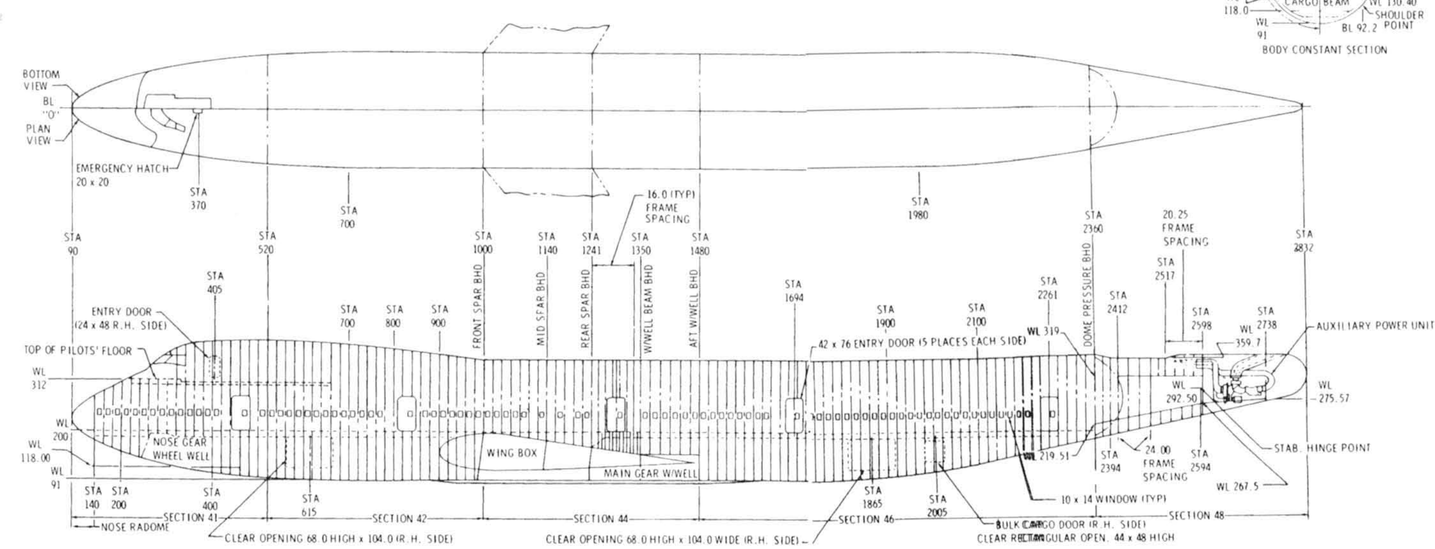
Multiple Redundancy

Multiple redundancy is a big feature of the 747 – Sutter even added a third spar in the wing to give it additional strength in the event of a mid-air collision. It has four separate hydraulic control systems, each driven by one engine and which are still controllable if only one system remains. Every main control surface, including the rudder, elevators, ailerons and flaps, is split into separate systems so that if one fails there would always be a back-up. In emergency, the main landing gear strut has its own extension system that electrically unlocks the gear and

The huge cabin width of the 747 that enables two aisles and ten-abreast seating in a 3-4-3 layout. Boeing



***(Below)* 747 fuselage.**



Another serious problem encountered during development of the 747 was emergency evacuation; this manifested itself early in the programme. Before full FAA 747 Type Approval could be obtained, Boeing had to demonstrate that evacuating 350–400 passengers by the ninety-second rule as laid down by the FAA could be carried out. The FAA was not entirely satisfied with emergency passenger evacuation from the upper deck, and wanted these doors redesigned. This photo of a later 747-300 model shows the slide/raft arrangement being successfully employed during a test from the upper deck. After ditching, with the aircraft settled on the water, the doors would be opened and the slide/rafts automatically deployed. With passengers, crew, survival packs, emergency beacons and first-aid kits aboard, the slide/rafts can then be detached and allowed to drift from the sinking aircraft. Full FAA 747 Type Approval was obtained on 31 December 1969 with the issuing of Approved Type Certificate A20WE. Boeing

the wheel-well doors to allow the gear to 'fall out' and lock in the 'down' position.

The fuel system, like many other major systems on the 747, was given multiple back-ups. Initially, on the 747-100 series, the fuel load was 47,210 US gallons, later increased to 51,430 US gallons in the -20B series; this was stored in four main tanks (one for each engine), two reserve tanks and a large centre-wing tank. Two electrically boosted pumps fed fuel from each main tank to its respective engine, while a cross-feed manifold and valves allowed fuel in any of the tanks to be fed to any or all of the engines. A suction-feed capability was designed as a back-up in case the boost pumps should fail. The boost pumps in the centre tank overrode the wing-tank pumps until the centre tank had emptied. To lessen the risk of fire in the event of an impact, the underbelly itself would first act as a cushion, and it was intended that the risk of fire spreading from the engines and the wing tanks would be contained by the way the structure was designed. The engines were podded anyway, and the system design was such that any leakage of fuel or vapour in the integral fuel tanks should be contained by an elaborate structure of seals and compartmentalization.

Propulsion Problems

The technical problems encountered throughout the construction programme were exacerbated by managerial and political shenanigans, and other unnecessary tribulations involving everyone from the US government to P&W, Pan Am, Boeing and other airlines (*see Wide Body* by Cliff Irving). All this conspired to put the brakes on the entire 747 project, and it was obvious to Stamper that his hoped-for first flight date of 17 December 1968 for N7470, the first aircraft, would not be met. The wings and fuselage were mated in mid-June, but neither the landing gear nor the JT9D engine were ready. The JT9D had been test-run for the first time at East Hartford in December 1966, and in the late spring of 1968 a B-52 was converted to a flying testbed for further testing, and a single JT9D engine mounted where two J57s had been. Static testing of the JT9D was completed by April 1969. The omens however, were not good.

The JT9D was showing alarming signs of being prone to power surges and stalling. Also, early testing showed that the forty-six high-pressure compressor fan blades – capable of pumping in excess of 1,000lb (454kg) of air per second at full power at sea level – would rub against their casings at the bottom of the engine. While this was anticipated, Pratt & Whitney were completely unprepared for a further problem with the engine which now occurred during the flight certification test stage, one which could not have been induced during static testing: the normally circular turbine casings were being bent out of shape – in effect they were being 'ovalized' – and this was in turn causing the high-pressure turbine blades to rub against the

sides of the casings. Needless to say, this greatly affected the engine's efficiency and therefore its overall performance.

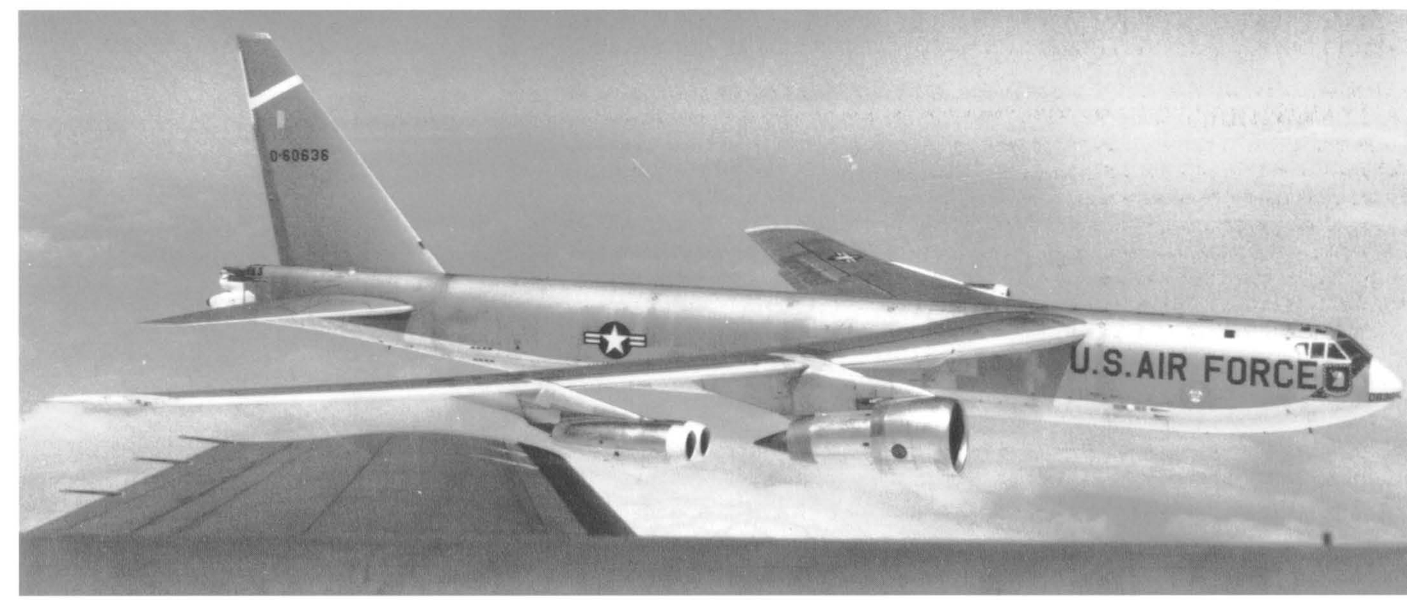
Pratt & Whitney suggested that this excessive bend resulted from Boeing's decision to mate, or 'grab' the JT9D to the wing by a single thrust link on the turbine case, and not – as on previous Boeing jetliners – by a thrust link fitted to the engine compressor casing. (Boeing had chosen the former method as a means of transferring the power of the engine to the airframe to save pylon, or strut, structural weight. The JT9D was also mounted well forward to improve flow interaction between the pod and the wing to reduce drag and cut down the potential for wing flutter.)

At Boeing, Everette L. Webb, the head of the technical staff, drew on his experience

747-100 Characteristics

Engine	*JT9D-7A*	*JT9D-7A W**	*JT9D-7A*	*JT9D-7A W**
Takeoff thrust, sea level (lb)	46,950	48,570	46,950	48,570
Maximum taxi weight (lb)	713,000	713,000	738,000	738,000
Maximum brake release gross weight (lb)	710,000	712,000	733,000	735,000
Design landing weight (lb)	564,000	564,000	564,000	564,000
Maximum zero fuel weight (lb)	526,500	526,500	526,500	526,500
Operating empty weight (lb)	356,900	357,400	357,100	357,600
Structural payload (lb)	169,600	169,100	169,400	168,900
Cargo/baggage volume (cu ft)	6,190	6,190	6,190	6,190
Fuel capacity (galls)	47,210	47,210	47,210	47,210

** options*



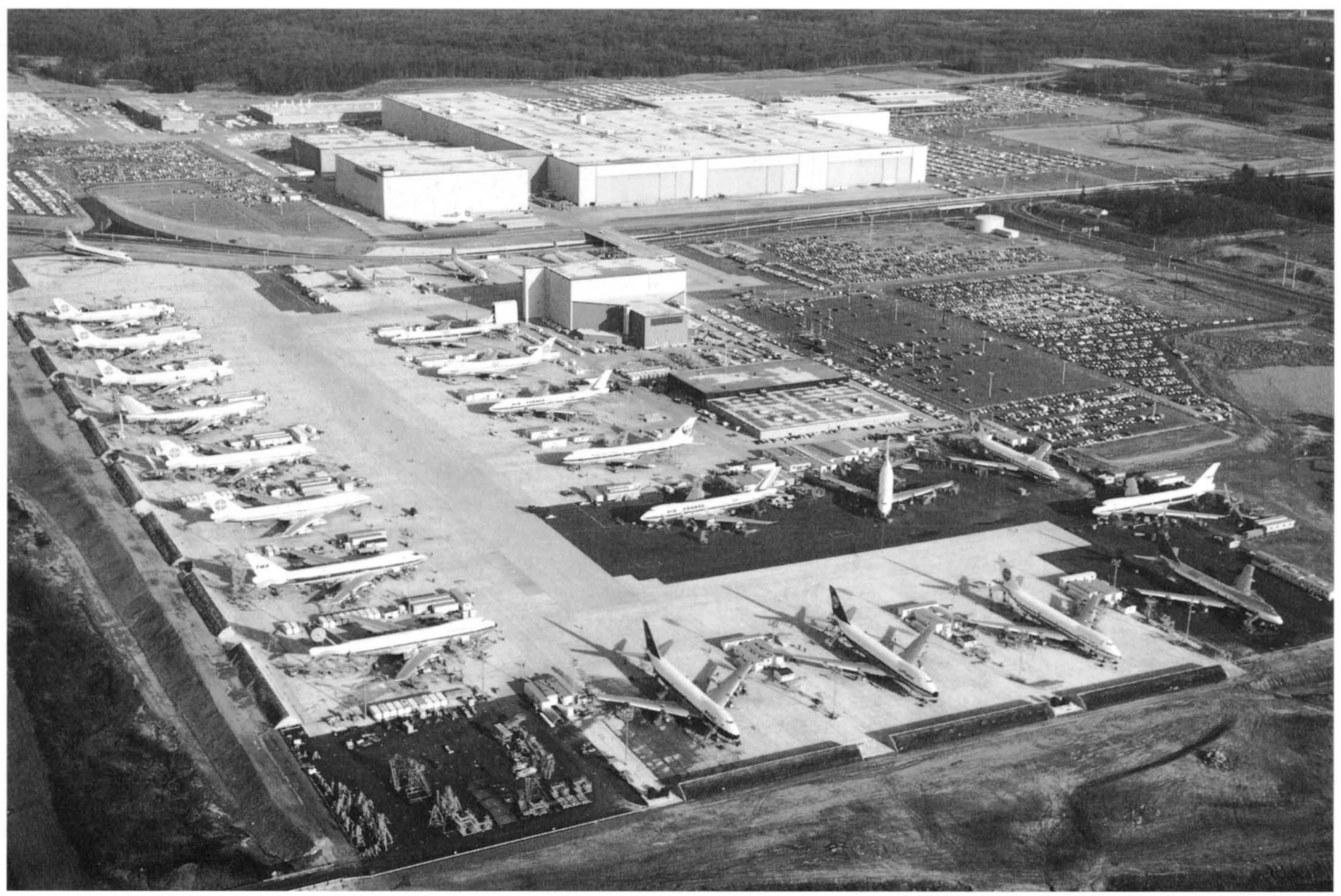
The JT9D was test-run for the first time at East Hartford in December 1966, and in the late spring of 1968 a B-52 was converted to a flying testbed for further testing, a single JT9D engine being mounted where two J57s had been situated before. The JT9D showed alarming signs of being prone to power surges and stalling, and further testing resulted in the normally circular turbine casings being bent out of shape, or 'ovalized'. This in turn caused the high-pressure turbine blades to rub against the sides of the casing. Obviously this problem greatly affected the engine's efficiency and therefore its overall performance. Boeing

of stresses gained during the 727 programme and, using engine drawings supplied by P&W, ran a computer programme to prove that it was not the design of the mounting that was at fault, but that the problems were being caused by the engine itself. Pratt & Whitney carried out a series of modifications and changes to the internal workings of the engine, but the bending problems refused to go away; if anything, by July 1969 they had grown worse. The JT9D was the first commercial large-fan engine and it therefore introduced many new, innovative features, including an annular, ring-shaped combustion chamber which helped to make the engine shorter than the previous turbine engines. Also the dimensions of the rear end of the JT9D were markedly different to the size of the 8ft-(2.4m-) diameter fan assembly at the front. Boeing showed that under certain flight conditions, including the high angle of attack during take-off, the contrasting size of the huge diameter front fan and the turbines behind it were inducing bending stresses in the turbine casing, which soon became distorted. Finally P&W agreed to look at the outside of the engine.

Strengthening the exhaust casing and adding a stiffening ring at the high-pressure

(Left) **Static testing of the JT9D was completed by April 1969 and large-scale fatigue tests were started on an outside rig at Everett. Fatigue-testing involved the entire airframe being continuously pressurized and depressurized, and moving parts were cycled in and out as the 747 was put through continuous cycles to simulate a lifetime of operations.** Boeing

Delays were caused by engine problems, and by early 1970 a new 747 was coming off the production line once every three days with no upgraded engines for it. Instead, some thirty 747 airframes were parked on the Everett ramp with 9,600lb (4,350kg) concrete blocks hanging off the wings where the engines should have been until enough JT9Ds could be delivered. Behind the 'gliders', or the 'aluminium avalanche' as Boeing engineers called this phenomenon, is the main assembly building, built at a cost of $200 million. The single roof reaches to a height of ten storeys, spans 63 acres and contains the largest volume of any building in the world, some 205 million cubic feet, 70 million cubic feet more than the Vertical Assembly Building at the Kennedy Space Center, previously the world's largest building. In 1980, the main assembly building was enlarged to 291 million cubic feet to further accommodate Boeing 767 production, and today, major parts of the 747 and 767 manufacturing subassembly and final assembly functions are all housed under one roof. Boeing



turbine case cut the ovalizing tendency by 12 per cent at the exhaust and 15 per cent at the high-pressure turbine, but P&W could not completely eradicate the bending. In fact this problem was only finally solved by a series of measures: first, two 45-degree thrust-transfer members were added to two other points on the exhaust casing: these changes reduced bending by 30 per cent and ovality by 102 per cent. Then a 45-degree 'Y-frame' was fitted to transfer the thrust loads to the intermediate compressor casing; and finally, an inverted 60-degree 'Y-frame' prevented all tendency of the turbine casing to ovalize, and reduced bending by as much as 80 per cent.

All this took time, however, particularly given the fact that before they reached Everett, the JT9Ds had still to be flown to Chula Vista, California, where the nacelles were manufactured and installed by the Rohr Corporation. As a consequence, the JT9D was still not ready by the end of 1969. Furthermore the delays had a knock-on effect and created an embarrassing situation early in 1970, when 747s were coming off the production lines at the rate of one every three days, and there were no upgraded engines for them. Instead, some thirty 747 airframes were parked on the Everett ramp with 9,600lb (4,355kg) concrete blocks hanging off the wings where the engines should have been, waiting until enough JT9Ds could be delivered. (Boeing engineers called them 'gliders', and the phenomenon of so many 747s without engines went down in folklore as the 'aluminium avalanche'.) Eventually P&W managed to get the engine to produce 43,500lb (19,732kg) of thrust, and finally 45,000lb (20,412kg), but the cost to the company was enormous.

Delivery

Elsewhere, news of the emergent Lockheed TriStar and Douglas DC-10 jets heightened the tension for everyone in the pressure-cooker atmosphere at Everett, while cost-overruns (the 747 programme was the largest drain on cash Boeing had ever experienced) were reaching crisis point. Ultimately, 48-year-old Thornton A. Wilson, who had been handed the reins by 68-year-old Bill Allen on 29 April 1968, would have to initiate a massive cost-cutting regime to pull the company back from the brink of bankruptcy in December 1969. Within eighteen months 'T', as he was called, made redundant no fewer than 60,000 employees, half of them production workers. The American banks now needed to see something tangible for their money, especially since the hope that the first 747 would be ready to fly on 17 December was a forlorn one.

The roll-out day was set for Monday 30 September, and at that particular point in time the 747 still had no landing gear; moreover although the engines were mounted, their only real purpose, apart from making the aircraft appear outwardly almost ready to fly, was as a counterweight to prevent N7470 from sitting on its tail. The pre-production problems also had a knock-on effect on the other 747s on the line. A total of five 747s were earmarked for the test programme, but all of these aircraft were behind schedule. For instance N747PA, the second 747, and also destined as the first aircraft for Pan Am (*Clipper Young American*), was scheduled to fly on 29 January 1969, but in the event, this aircraft would not be rolled out until a month later.

As regards marketing, sales of the 747 to airlines in 1968 looked very promising

By roll-out day, Monday 30 September 1968, Boeing had received orders totalling almost 200 aircraft from twenty-six airlines. N7470, resplendent in its white livery with a red stripe down the window line, and the logos of its airline customers adorning the nose, was towed out. The run-up to the roll-out of the first 747 had been fraught with frenetic activity to ensure that everything possible would be in place. As it turned out, roll-out day was a great success. Boeing

indeed, and predictions were that Boeing would soon increase production to 8½ aircraft a month; by the time the first 747-100 was decreed ready for rollout late in 1968, Boeing had received orders totalling almost 200 aircraft from twenty-six airlines. Pan Am had taken up some of its options on more 747s: on 7 May 1968, Juan Trippe had retired as chairman of Pan Am and handed over to Harold Gray, who that summer signed contracts for eight more 747s at a cost of $175 million to bring the airline's total order to thirty-three aircraft. In fact, Pan Am's spending on the 747 project surpassed a billion dollars that summer, with the investment in the new Worldport and 747 maintenance facility at Kennedy Airport.

The run-up to the rollout of the first 747 was fraught with frenetic activity to ensure that everything possible would be in place for Monday 30 September 1968. The day dawned chilly and the sky was thickly overcast, but any greyness was soon dispelled once the ceremonies began, the Everett High School, their band in front of the opening hangar, proceeding with Elgar's march, 'Pomp and Circumstance'. Inside the plant, twenty-six stewardesses, one from each airline that had ordered 747s, posed for photos under the cavernous body of N7470. There was a half-hour of speeches, led by the master of ceremonies, T. Wilson – and only then did Matt Stamper order the huge hangar door, the size of a football field to be opened: a low-slung tractor tugged the huge airliner slowly forward into the crowded amphitheatre, and magically the sun appeared, illuminating this white whale with a red stripe down its window line, logos of the twenty-six airline customers adorning its nose. Once the massive tail of the aircraft was clear of the doors, the tug came to a stop beside the reviewing stand. N7470 was then surrounded by the flock of stewardesses, each one carrying a bottle of champagne: at a signal from Stamper they approached the 747, then waited to be counted before breaking their bottles of bubbly on pre-designated parts of the aircraft. This was meant to be a simultaneous action, but as some of the hostesses did not understand English, the bottles were actually smashed on the aircraft at random. Overhead, a 707, a 727 and a 737, delayed by the weather, made low passes over the plant.

Once all the razzmatazz of the rollout had subsided there was a growing realization that, while there were still a myriad problems to rectify concerning the engines and the airframe, the 747 was now about to enter a crucial phase of its metamorphism. The P&W JT9Ds had not yet been run on the 747 and therefore the aircraft's hydraulic, electrical and fuel systems had not been tried either. Taxiing trials were now due to be completed and the first flight with all the attendant glare of publicity, would be followed by extensive airframe testing in flight. Allen's and Trippe's combined dream was about to be realized.

N7470 was surrounded by twenty-six stewardesses – one from each of the airline customers – each carrying a bottle of champagne, which they broke on pre-designated parts of the aircraft. It had been intended that this would be a simultaneous action, but as some of the hostesses did not understand English, the bottles were smashed on the aircraft at random. Boeing

CHAPTER THREE

The Spacious Age

The winter of 1968–9 was one of the worst in Washington State's history, with driving winds and snow squalls making work almost unbearable at Pine Field, where flight-testing of the first 747 would begin. Connie Smith, head of the pre-flight unit, was loath to release the aircraft to flight operations until he was satisfied that the untried JT9Ds could provide stable power – they were known to be extremely sensitive to wind effects which could cause 'flame out', or worse, they could stall. (An engine stall could be caused either by encountering a 10-knot crosswind, or if the wind blew directly into the JT9D's tailpipe.)

The test-flight crew was led by chief test pilot Jack Waddell. As well as being an experienced pilot (he had flown Navy fighters in World War II and latterly had been the project pilot on the C5A), Waddell was also an accomplished aeronautical engineer. For the 747's test-flight programme he had selected as his co-pilot Brien Wygle, who had been chief test pilot on the 737, and Jess Wallick as his flight engineer. Both Waddell and Wallick had been involved from the outset with the 747 programme and had collaborated in parts of the design, especially the flight deck. They were understandably reticent to fly the aircraft until these problems were sorted out, but the flight-test programme was already nearly eight weeks behind schedule, and the first 747 was due to be delivered to Pan Am by the end of December 1969.

It was not until the end of January 1969 that N7470 was passed for flight operations and could taxi out to the runway for the ground run-throughs. Sixty thousand pounds (27,216kg) of test equipment and 1,000lb (454kg) of water ballast in rows of 55-US gallon (208-litre) aluminium beer kegs had been loaded on board the 747. The 747's balance could be varied by pumping water from one group of beer kegs to another. More kegs were situated in the forward cargo hold, below the main deck, and to bring the total weight up to just over 476,000lb (215,914kg), mailbags were loaded in the aft passenger cabin.

Jess Wallick, flight engineer (left), Jack Waddell, chief test pilot (centre) and Brien Wygle, co-pilot (right). Boeing

Cameras were installed to monitor crucial areas such as the leading edge of the wing, the flight crew, instrument panels and the landing gear, and to record the take-off.

By the end of the first week of February, Waddell had taken the N7470 to the brink of take-off, at 150mph (240km/h). At this time he was not enthused at the prospect of taking the aircraft off the tarmac with the P&W engines in their present state of development, but the only way of simulating the angle of attack (and the change of direction of the air entering the engines in the nose-up attitude) was to take the 747 actually off the ground and into the air. His main concern was that all four engines would stall at the same time, and without engine power he would lose his hydraulics and, consequently, all the controls. Joe Sutter therefore fitted the test aircraft with back-up electrical power provided by a bank of heavy-duty batteries to operate the hydraulics in the event

of total engine failure. Waddell was also concerned with having to judge the landing of the 747 from a flight deck that was so very much higher than anything he had flown before. He therefore had the Boeing engineers construct a mock-up of the flight deck and part of the nose, and mount it 29ft (9m) up on top of a rig simulating the sixteen-wheel landing gear. Painted bright orange with a grinning Halloween mask with black triangular eyes and toothy grin, the contraption became known as 'Waddell's Wagon', and was towed around the airfield by a truck with Waddell sitting in the 'cockpit' familiarizing himself with seeing the runway from on high. In fact he had no need to worry about the height of the flight deck from the tarmac, and his fears regarding the quality of the 747's engines proved groundless: they behaved impeccably, and by Sunday 9 February he was confident enough to try for the first flight, as soon as the weather lifted.

Waddell was concerned with having to judge the landing of the 747 from such a high flight deck, so he had Boeing engineers construct a mock-up of the flight deck and part of the nose, and mounted it 29ft (9m) up on top of a rig simulating the sixteen-wheel landing gear. Printed bright orange and with a grinning Halloween mask with black triangular eyes and toothy grin, the contraption was known as 'Waddell's Wagon' and was towed around the airfield by a truck, with Waddell sitting in the 'cockpit' familiarizing himself with seeing the runway from on high. Boeing

Bill Allen, informed that there was a possibility that the 747 would at last make its first flight, returned on the Saturday evening from visiting Jaun Trippe at his retirement home in the Bahamas. By early Sunday morning the clouds had lifted slightly although the wind was gusting at between 10 and 15mph (16 and 24km/h), from the south-east. A little after 9am, the pilot of a 707 that was being flight-tested from Boeing field called the flight operations centre at Everett and reported a clearance coming in from the west, toward the San Juan Islands. Waddell conferred with the 707 pilot, and decided the conditions would be within bounds to enable him to take the 747 up for its first flight. Allen walked to the aircraft with Waddell, whose face betrayed a little anxiety – not surprising in view of the task ahead. His boss added unnecessarily to the pilot's already heavy responsibility by saying, 'Jack, I hope you understand that the future of the company rides with you guys this morning.' Perhaps Allen was recalling the historic first flight of the 707 when 'Tex' Johnson had rolled the airliner after take-off.

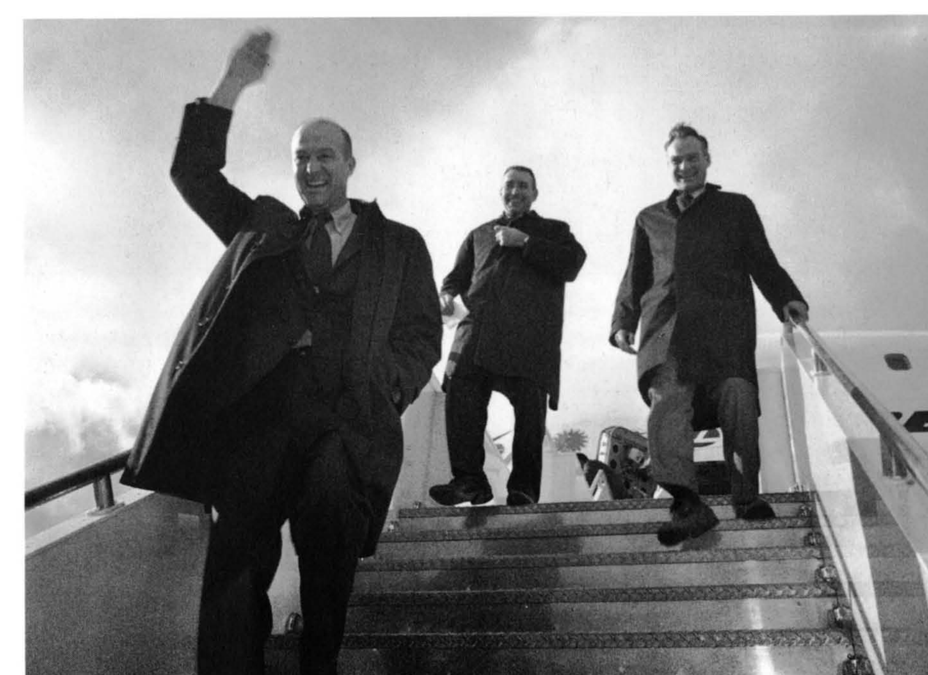
Waddell climbed aboard, and the crew took up their positions on the flight deck. The first engine was started at 11:07 hours and within four minutes all four were running. Waddell set the stabilizer at an angle of 5 degrees and called for the chase plane, an F-86 Sabre flown by Paul Bennett, to begin take off. By the time Waddell was ready to roll he could see buses moving on the runway, and he had to call the tower to tell them to move further back before he could taxi out. There was still thick cloud cover at 1,500ft (450m), but the wind had dropped slightly Waddell taxied out towards the northern end of the runway and held the brakes on while the JT9Ds reached take-off thrust. When Wallick announced that he had 'four stable engines', his pilot released the brakes and at just after 11:35 hours the 747 hurtled along the runway. Half way along, at 4,500 feet and at 150mph (243km/h), Waddell felt the nose coming up and called 'Rotate'. Much to the excitement of everyone, the 747 lifted seemingly effortlessly into the air – though the efflux from the engines was too much for one photographer nearby who was promptly bowled over backwards by the blasts. Finally the gear unstuck, and the turbines accelerated the aircraft up and away. There was no need

On Sunday 9 February 1969 Jack Waddell lifted N7470 into the air for the first time accompanied by the chase plane, an F-86 Sabre flown by Paul Bennett, seen here closing in so that Bennett can inspect the flying surfaces and the gear. He reported that the engines were burning clean and that there was no smoke. Waddell brought N7470 in over Everett and put the aircraft down safely, if a little faster than he wanted to, because of a fault with the flaps. In all other respects the 747, which had been airborne for an hour and sixteen minutes, flew exceptionally well. Boeing

for Waddell to put the nose down and carry out an emergency stop, and the huge airliner sailed majestically away to altitude leaving those on the ground to wax lyrical and swell with pride. Joe Sutter's wife Nancy reportedly burst into tears with the emotion of it all.

Waddell reported that the 747 was surprisingly light on the controls and felt good. He decided to carry out a shallow turn to port, all the way through 270 degrees, in order to bring the aircraft back over the field to give the assembled ranks of photographers an early opportunity to take more photos. Then the Sabre chase plane came in closer, and Bennett inspected the flying surfaces and the gear: he reported that the engines were burning clean, and that there was no smoke. Waddell playfully rolled the 747 30 degrees to the left, and then to the right. So far so good, though Wallick reported that the number one engine was running 30 degrees hotter than the rest and that there was no sign of the temperature dropping. Undeterred at this news, Waddell continued climbing at 400ft (122m) a minute until, just after 11:42 hours, they broke into clear, brilliant sky and smoother air.

With the airspeed now registering 160 knots, Waddell tried some fairly gentle pitch manoeuvres before climbing the aircraft through 12,000ft (3,658m) to 15,000ft (4,572m) and 280mph (450km/h) over the Strait of Juan de Fuca. Shortly before noon he initiated the part of the test plan designed to test the fail-safe systems. He shut down the first independent hydraulic system, and when the 747



747 chief test pilot Jack Waddell, Jess Wallick, flight engineer, and Brien Wygle, co-pilot, walk triumphantly down the steps of N7470 after the first flight on 9 February 1969. Boeing

On 15 February, Waddell took N7470 up again, on a flight lasting two hours eighteen minutes, and this time the flaps were successfully retracted. Checks were carried out on the fuel-feed system, and the first full retraction and lowering of the landing gear in flight was made. Boeing

handled as if nothing had happened, he shut down the second system; this effectively shut down the left outboard aileron, the left outboard elevator and the right inboard elevator, and he had only half power to both inboard ailerons and to both rudders. Everything that the simulator had predicted would happen was thankfully coming true and Waddell was still able to fly the aircraft on the two remaining systems with no noticeable loss of control. (If anything really untoward went wrong during the test flight and the crew had to abandon the aircraft they were to leave via an emergency exit shaft with a pole running down from the upper deck to the floor of the cargo hold 20ft (6m) below. Once there, the crew would have to pull a handle to activate a hydraulic ram to drive open the cargo door. Outside meanwhile, a retractable spoiler on the leading edge of the cargo compartment would open simultaneously, deflecting the air flow as the three men parachuted to safety.)

Waddell then restored all his hydraulic power, and with the gear remaining in the 'down' position (gear and the flaps were to be raised and lowered again at least once during the flight), successfully put the aircraft through more tests. He checked on trim and stability, flew with unbalanced power settings, and then tried to put the aircraft into a Dutch roll by kicking the rudder pedal – but the big tail did its job and the 747 refused. Unlike the 707, which had rolled so badly on a test flight that the aircraft had fatally discarded its engines. The 747, whose tail-fin area was 40 per cent greater than its predecessor, had no such vices. Everyone was elated.

Waddell now lowered the triple-slotted flaps from 25 to 30 degrees. Drag increased as the flaps extended back and downwards, and then there was a disconcerting 'clunk' as they hit 30 degrees, followed by vibration.

N7470 taking off from Boeing Field during tests, which revealed wing flutter, or instability, problems. These led to the fuel-feed system having to be adjusted to alter the weight distribution to acceptable limits. Boeing

Waddell restored the flaps to 25 degrees and sent Wallick back to investigate. Wallick could see that a section of the right-hand flaps had shaken loose and wedged itself in a gap between the slots, and it was this which was vibrating. (It was discovered later that a bearing housing under the canoes had failed.) Waddell prudently decided to terminate the flight with one hour still to run, and return to Everett. By the time they were back over land and heading toward Lake Roesiger, the 727 which had the press and Bill Allen on board, caught them up and came close enough for air-to-air photos to be taken of the 747 and the Sabre chase plane off its port wing. Waddell brought N7470 in over Everett and put the aircraft down safely, if a little faster than he wanted to, because of the faulty flaps. The 747 had been airborne for an hour and sixteen minutes.

Six days later, on 15 February, Waddell took N7470 up again, on a flight lasting two hours eighteen minutes, and this time the flaps were successfully retracted. Checks were carried out on the fuel-feed system, and the first full retraction and lowering of the landing gear in flight was made. The flaps were set at various angles and tested. On 17 February, N7470 was flown on a twenty-three minute flight to retest flap handling at 25 degrees, and checks were made on the main landing gear. Next day the 747 made two flights, totalling three hours six minutes, in which further approach and landing flaps tests were conducted, as well as the first checks on the nacelle cooling of the engines. In fact the JT9D1 powerplants remained one of the major troublesome factors in the 747 development, with no fewer than eighty-seven engines breaking down and fifty-five engine changes having to be made during the test programme – that is, between February and December 1969.

After more flap-testing on 24 February the next day, Waddell flew N7470 on a static pressure and airspeed survey flight lasting just over two hours. Then Bill Allen joined him on the flight deck for the first time, and he flew the aircraft on the short twenty-eight minute hop across Puget Sound to Seattle and into Boeing Field where the second phase of flight-testing was to take place. By the end of the first phase, speeds of up to 287mph (462km/h) had been achieved, and altitudes of 20,000ft (6,100m) had been reached. While everyone knew that this overall performance was well below what was expected of the airliner, the speed soon reached Mach 0.84, or 623mph (1,002km/h), faster than any other airliner had ever done. However, Pan Am were still sticking to their expected specified speed of Mach 0.9, or 667mph (1,073km/h), which was finally achieved. The higher speeds, and adjustments to the fuel-feed system loadings, now presented Boeing with another, equally serious problem, one that would take six months to rectify.

Flutter, or instability, had begun to manifest itself at speeds of around Mach 0.86, and there was 'low damping' (wing shake) if the weight of the outer wing in particular was changed in any way. During flutter testing between March and August 1969 – often delayed because of the severe wintry conditions – the flight crew had to continually juggle the weight of the fuel between tanks to keep the wing from oscillating. Finally the fuel-feed system had to be adjusted to alter the weight distribution to acceptable limits. Another way in which flutter could be contained was to increase the stiffness of the wing, but this would have involved further costly and time-consuming structural changes. One of the areas in which the oscillation was markedly bad was the engine struts and nacelles supporting the bulbous P&W powerplants. Sutter and Everette Webb therefore tried to alleviate the flutter problem by actually *reducing* the stiffness in the struts, to give them more flexibility. This improvisation worked to a variable degree, but it was then found that more weight was needed in the outboard engine mountings (numbers one and four) so they could be used as counter-weights to the oscillating

Jack Waddell deliberately scraped the tail of N7470 along the runway to determine the lowest speed (VMU – 'velocity minimum unstick') at which the 747 will leave the ground safely. A wooden tail-skid was fitted to the underside of the rear fuselage to prevent damage. Boeing

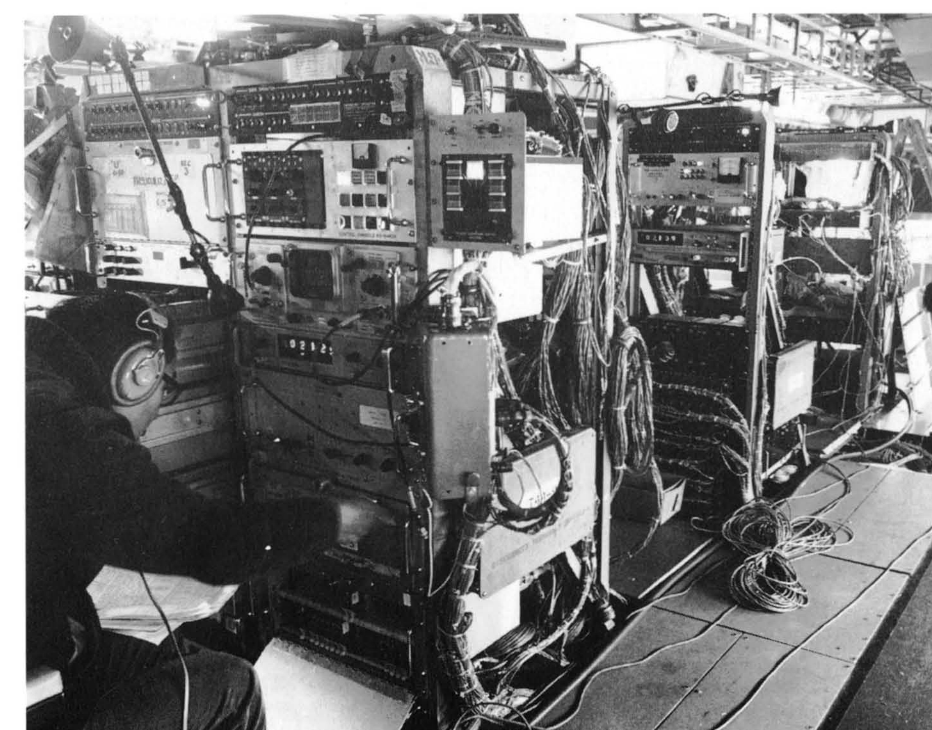
***(Below)* Boeing's newly elected President, T.A. Wilson (seated, wearing jacket) accompanied Jack Waddell and his test-flight crew for some of the VMU tests.** Boeing

wing problems. To avoid any further redesign, and because space inside the mountings was at a premium, bags containing 700lb (318kg) of 'spent'– that is depleted of its fissionable isotope – uranium pellets (the heaviest metal available) were embedded in numbers one and four engine struts of the test aircraft (although wing stiffening was used on the five aircraft used in the test programme).

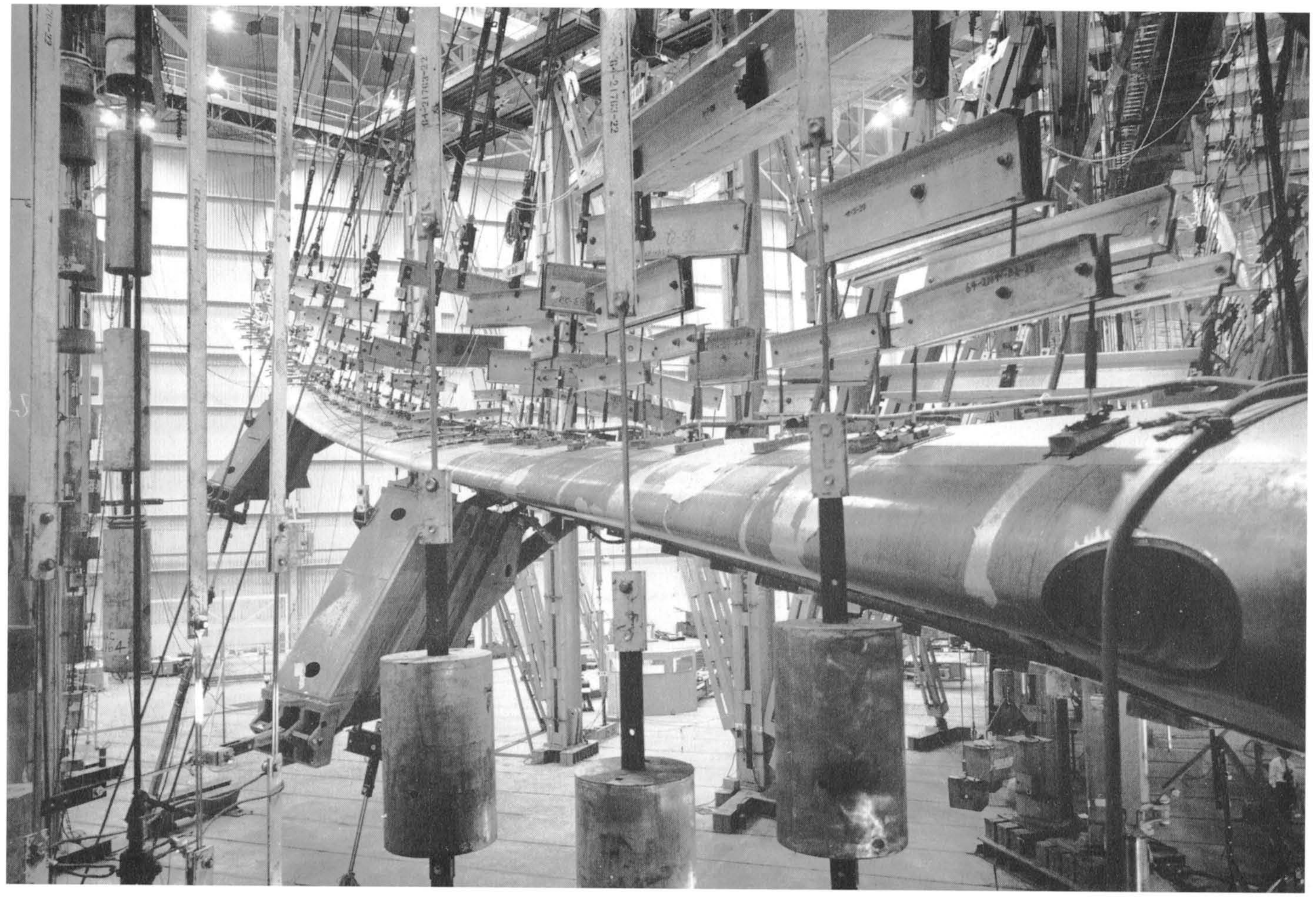
Meanwhile N747PA, the second 747, destined to be Pan Am's first aircraft (*Clipper Young America)*, was rolled out at Everett on 28 February 1969 – by which time twenty-seven airlines had ordered 160 aircraft. The aircraft flew for the first time on 11 April, more than a month later than scheduled. Before being issued to Pan Am it was assigned to test propulsion, fuel, and electro-mechanical and avionics systems. On 23 April, N731PA became the third 747 off the production line, even though it was actually designated as the fourth test aircraft. Later it was named *Clipper Bostonian* when in Pan Am service from 1970–81, and it became *Clipper Ocean Express* in 1981. It finally joined the test programme on 10 May, and was used for functional and reliability testing, as well as some electro-mechanical system evaluations before being delivered to Pan Am on 11 July 1970. Meanwhile on 8 May 1969, N93101, the fifth aircraft, and the first 747 for Trans World Airlines, had been rolled out. N93101 flew on 22 May and was assigned to test aerodynamics, stability and control before being delivered to TWA, on 18 August 1970. Finally on 16 May 1969, N732PA *Clipper Storm King*, the third test aircraft, which was delayed in production because of the need to fit a 32ft (10m)-long aluminium pole to the nose for gust measurement testing, was also rolled out at Everett. It eventually flew on 10 July 1969, and was used mostly for flight-load survey testing before being delivered to Pan Am on 13 July 1970.

Needing a boost, Boeing now sought to gain a quantum leap in publicity for the 747 programme. Bill Allen strongly suggested to 'T' Wilson that one of the test aircraft should be flown across the Atlantic to France early in June to take part in the 28th Paris Air Show. It would be especially satisfying for Boeing since Lockheed had considered, and had then dropped, the idea of flying the equally

***(Above)* Boeing engineers working flat out in the snow on the Pratt & Whitney JT9D engines. JT9Ds remained one of the major troublesome factors in the 747 development, with no fewer than eighty-seven engines breaking down and fifty-five engine changes having to be made during the entire test programme.** Boeing



Flight-test engineers preparing the 747 on-board test equipment during the certification programme for the aircraft. Boeing



The 747's 195ft 8in (59.2m) wide wings were designed to move up and down some 29ft (9m) at the tips to give the flexibility to cope with the effects of air turbulence on its surfaces. While the flight-test programme continued, a third airframe was deliberately tested to destruction by a combination of hydraulically actuated weights and pulleys. Boeing

Flight-testing included demonstrations of the 747's ability to carry a spare engine, complete in every way except for the fan blades and nose cowl, mounted under the left wing inboard of the number two engine. Fan blades were carried in shipping containers in the bulk cargo compartment. A nose cowl, fan cowl, and forward strut fairing was provided as part of the spare engine kit. The kit also contained a plug to cover the exhaust nozzle. Boeing

troubled C-5A to the show. Wilson conferred with Dix Loesch, head of flight-testing, to see if he had faith in the P&W powerplants powering the aircraft on a non-stop flight from Seattle to Paris, a distance of 5,160 miles (8,300km). Loesch decided that only N731PA, the fourth 747 off the production line and which had ten hours' flying time, could make the long trip safely. Initially Loesch said that he first wanted a full check of the systems on the aircraft, and wished to add another ten hours' flying time on the airframe and the engines, before it attempted a transatlantic flight, but after a few days, and with the engines functioning reliably enough, he dropped his precautionary stance. The only additional flying hours would be the eighteen-plus hours gained on the return flight to Paris.

Although N731PA was due to be delivered to Pan Am, it was still painted in Boeing colours. When Pan Am found out about the Paris flight, Boeing refused the airline's insistent decree that it be repainted in the blue and white livery of American's premier airline for fear of affecting the sales potential of the other carriers. Because N731PA would be carrying the full weight of fuel it was decided that rather than leave from Everett or the 10,000ft (3,050m) Boeing Field, the 747 would fly to Sea-Tac (Seattle-Tacoma) Airport and take off from the airport's longer, 12,000ft (3,660m) runway. In the early evening of 2 June, senior engineering test pilots Don Knutson and Jess Wallick, assisted by chief experimental flight engineer, P.J. de Roberts, took the 747 off for Paris Le Bourget, the same airport where Lindbergh had landed at the end of his epic flight, and set out across the north Atlantic for Europe. On board were Joe

Mal Stamper (left), Thornton 'T' Wilson (centre) and E.H. 'Tex' Boullioun, head of the airliner division, who accompanied Joe Sutter on the ground-breaking 747 flight to the Paris Air Show on 2 June 1969. Boeing

N747PA Clipper Young America **was the second 747-121 built and destined to be Pan Am's first aircraft (on 3 October 1970); it was rolled out at Everett on 28 February 1969, by which time twenty-seven airlines had ordered 160 aircraft.** Clipper Young America **flew for the first time on 11 April 1969, more than a month later than scheduled. Before being issued to the airline it was assigned to test propulsion, fuel, and electro-mechanical and avionics systems.** Clipper Young America **was renamed** Clipper Sea Lark **in 1980, and renamed** Clipper Juan Trippe **on 11 June 1981.** Boeing

Sutter, Mal Stamper and 'Tex' Boullioun, head of the airliner division.

Nine hours and eighteen minutes later on the morning of 3 June, the 747 arrived over Paris and touched down to share a hero's welcome with the first Anglo-French Concorde. VIPs, including Prince Philip and hundreds of airline chiefs, visited the 747 during its most memorable sojourn in Paris before it flew back to the north-west coast of the USA. All went well until it reached Moses Lake, just 140 miles (225km) from Boeing Field, where one of the engines developed a power surge and had to be shut down. Untroubled, the flight crew landed the 747 at Boeing Field without further incident, and having proved conclusively that the aircraft was more than capable of intercontinental airline operations, became once again, part of the 747's test programme.

747-121 N732PA, the third test aircraft, was delayed in production because of the need to fit a 32ft- (10m-) long aluminium pole to the nose for gust measurement testing; it was rolled out on 16 May 1969. N732PA (Clipper Storm King) **finally flew on 10 July 1969, and was used mostly for flight-load survey testing before being cleared for airline service. On 13 December 1969 it crashed at the end of a short flight from Everett to Renton. It was repaired and delivered to Pan Am on 13 July 1970.** Boeing

So far during the test programme (which finally resulted in the five 747s flying 1,449 hours in 1,013 flights), there had been the usual problems associated with testing a new type of aircraft and several minor incidents had occurred, but nothing untoward had really befallen any of the test aircraft. On 13 December 1969 the first serious accident in the test programme occurred when test aircraft number three, N732PA, flown by Ralph Cokely, left Everett for Renton where all its test equipment was to be removed and airline seating installed prior to delivery to Pan Am (as *Clipper Storm King*). No 747 had landed on the 5,280ft (1,609m) runway at Renton before, but N732PA weighed 390,000lb (176,900kg) and at this weight it was calculated that the distance from a 50ft (15m) altitude to a complete stop was 3,150ft (960m), without reverse thrust. At Renton a strong crosswind, gusting at times, and intermittent rain did little to help matters, but everyone was still certain that even on a wet runway the 747 would still stop safely in the available distance.

Cokely brought the 747 in over Lake Washington where the runway runs to the edge of the water, but the aircraft was not high enough to miss an earth bank on the shoreline 20ft (6m) short of the runway and 2ft 6in (76cm) below the runway threshold, and the right-hand body gear and wing gear were buckled in the impact. Hitting the runway, the 747 careered along it, showering sparks from its numbers three and four engines as the wing settled. Cokely managed to keep to the runway centreline, and the 747 came to a halt 3,500ft (1,000m) down the tarmac. Cokely was sacked for this incident. *Clipper Storm King* was repaired and eventually delivered to Pan Am in July 1970. In 1980 it was renamed *Clipper Ocean Telegraph*, and it served the airline until 1986 when it was relegated to storage in the Arizona desert. In 1989 the 747 was taken out of storage and converted to a 747-121SCD cargo aircraft.

Behind the scenes there was added drama, even at this late stage. Formal FAA certification for the 747 had still not been issued – although the FAA had determined that the engine problems would not compromise safety and had passed these, it was not entirely satisfied with emergency passenger evacuation from the upper deck and wanted these doors redesigned. Pan Am, aggrieved at the lower level of performance on the 747 to that originally promised (it was still 7 per cent short on range), now threatened to withhold $4 million from the final payment of each aircraft until Boeing had corrected several problems. As December dawned, Boeing met brinkmanship with brinkmanship, even threatening to sell the first 747s to TWA instead of to Pan Am. By this time Boeing was in severe financial hardship – final 747 development costs were later put at $750 million – and the recession, which had begun towards the end of 1968, was really beginning to bite.

A compromise ensued whereby Pan Am would withhold $2 million from the final payment on each 747 delivered until the problems, mostly with the engines, were rectified, paying the remainder in instalments. Finally, on 13 December 1969, N733PA *Clipper Young America* became the first 747 to be delivered to Pan Am, when it was flown from Everett non-stop to Nassau in the Bahamas, with a cargo of freight, and then on to the Pan Am complex at Kennedy Airport in New York. A week later, on 19 December, N734PA *Clipper Flying Cloud* – in 1980 it was renamed *Clipper Champion of the Seas* – followed. (Full FAA 747 Type Approval was obtained on 31 December 1969 with the issuing of Approved Type Certificate A20WE.)

747-121 N732PA Clipper Storm King (Clipper Ocean Telegraph **from 1980) looking none the worse for its accident, at London-Heathrow on 3 September 1980.** David Lee

Deliveries of 747-121 production models to Pan Am began on 12 December 1969. The airline flew over 300 employees from New York to London on 12 January 1970. Clipper Constitution, **which had been delivered just three days earlier, landed at Heathrow airport three hours late after one of its P&W JT9D fan-jet engines gave trouble and had to be changed. On 21 January 1970 Pan-American began a scheduled 747 commercial service with non-stop flights between New York and London when N736PA** Clipper Victor **completed the flight after N733PA** Clipper Young America **had suffered engine problems at JFK Airport.** Author's collection

(Above) **747-121 N737PA** Clipper Red Jacket, **delivered to Pan Am on 21 January 1970, pictured landing at Heathrow Airport. In 1980 this aircraft was renamed** Clipper Ocean Herald. Ron Green

(Left) **In March 1970 Trans World Airlines began operating the 747-131 on its New York to Los Angeles service, and in March 1973, on its New York to London route. Later that same year, TWA began 747 operations between the US and Paris and Rome.** Author's collection

By the end of 1970, seven US airlines were operating 747-100s: Pan Am, American, Continental, Northwest Orient, United, National and Delta (the last two on domestic routes only). Pictured is a Northwest Orient 747-151 (nine of which were ordered). Boeing

747-130 N1800B of Aerolineas Argentinas in flight. This aircraft, the twelfth 747 built, first flew on 18 February 1970 and was delivered as D-ABYA Nordrhein-Westfalen **to Lufthansa, the first overseas airline to buy the 747, on 10 March. In April 1970 D-ABYA entered Lufthansa service on the Frankfurt–New York route, where it replaced 707s. It is still in service with Tower Air, registered N603FF** Suzie. Boeing

Specification – 747-100	
Powerplant:	Four 43,500lb (19,700kg) Pratt & Whitney JT9D-3, 52,000lb (23,600kg) General Electric CF6-50E or 50,100lb (22,700kg) Rolls-Royce RB211-534B; fuel capacity 47,210–53,160 US gal (178,690–201,210ltr).
Weights:	Empty 348,816–370,816lb (158,223–168,202kg); gross 710,000–735,000lb (329,000–333,000kg).
Dimensions:	Length 231ft 4in (70.50m); height 63ft 5in (19.47m); wingspan 195ft 8in (59.6m); wing area 5,500sq ft (511sq m).
Performance:	Cruising speed 604mph (972km/h) Ceiling 45,000ft (13,700m) Range 5,527 miles (8,893km).
Capacity:	374–490 passengers (typical), 516 passengers (maximum).

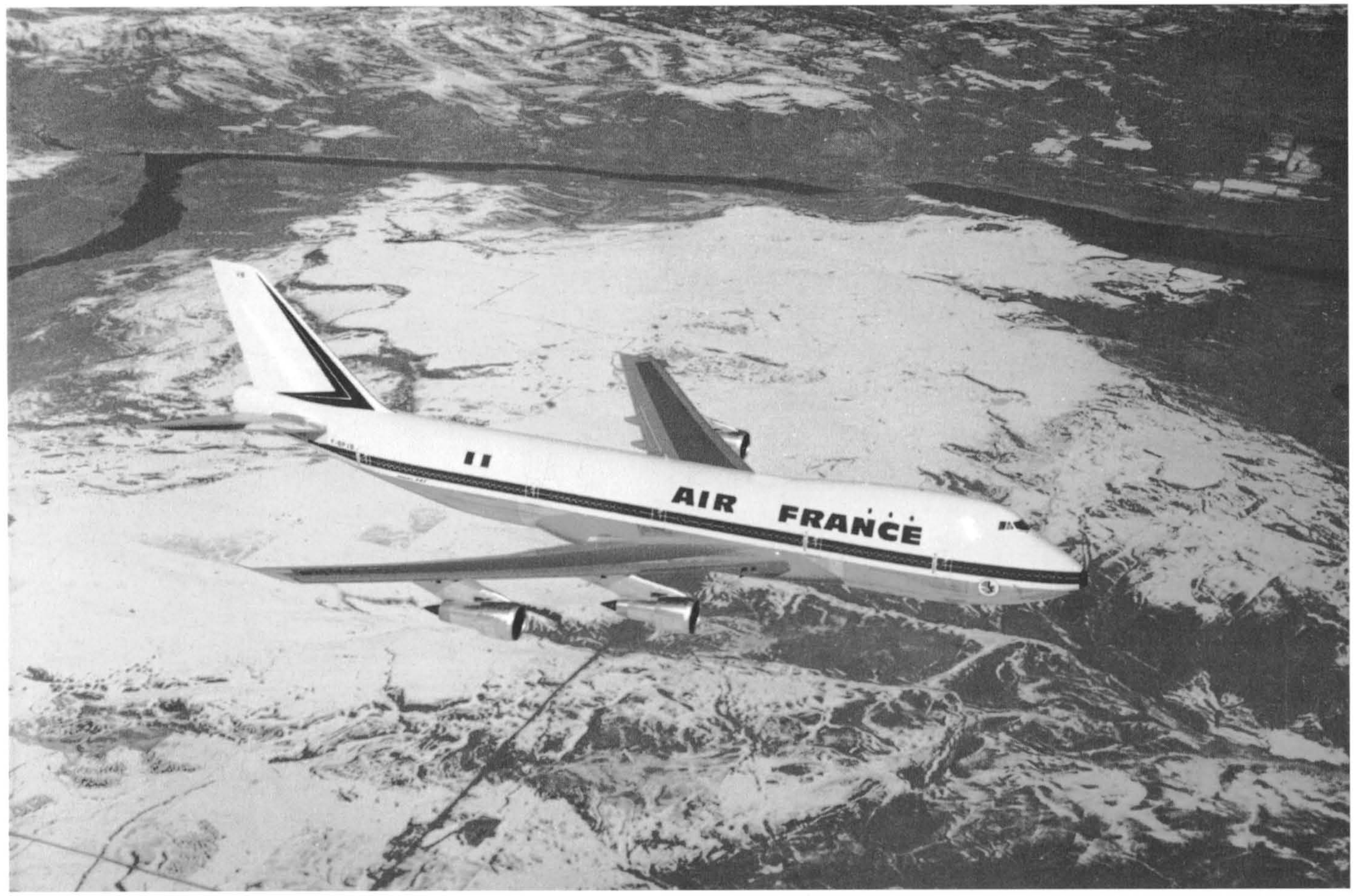
Into Service at Last

On 15 January 1970 Pat Nixon, the President's wife, christened N733PA *Clipper Young America* at Dulles Airport, Washington DC. Pan Am chose this aircraft to make the first flight across the Atlantic with paying passengers six days later. On a bleak, bitterly cold evening at Dulles on 21 January, 336 passengers – who had reserved their seats two years earlier at a cost of $375 for a first-class one-way ticket – three flight crew (headed by Captain Bob Weeks, New York chief pilot), and eighteen cabin attendants boarded *Clipper Young America* for the first commercial flight of the 747, to London-Heathrow.

Delayed by problems with the doors and the cargo hold, there were further problems when Weeks tried to start N733PA's engines. Gusting winds, which were blowing off the mudflats of Jamaica Bay, blew into the JT9Ds' tailpipes, restricting the flow of compressed air and exhaust gas and causing the engines to surge and produce temperature rises. The crew finally managed to stabilize the engines for take-off, and at 7.29pm, B733PA taxied out for take-off; but almost immediately it had to return to the terminal again when the number four engine exhaust temperature ran too high. (Later the fault was traced to an insensitive barometric fuel-control system which finally failed due to the high crosswind.) All the passengers had to be disembarked, and were bussed to the terminal for meals in the restaurants while Pan Am worked out what it could do to prevent the occasion turning into a public relations disaster.

Finally there was only one solution, and that was to replace the ailing *Clipper Young America* with a substitute aircraft, N736PA *Clipper Victor*, which had been delivered to the airline only the day before, and was to be used for training. Delayed by an air traffic controllers' dispute, *Clipper Victor* finally taxied out at around 1.30 in the morning and at 1.50 took off for the flight to London. Much to the relief of Pan Am and everyone else, no further serious problems were encountered and the flight was made without incident – and without the in-flight movies, since the reserve 747 was not equipped for showing them. *Clipper Victor* covered the route in just 6 hours 16 minutes, and landed at London-Heathrow to a great reception.

Unfortunately the 747's introduction into service coincided with a sharp



(Top) By the end of 1970, three other European airlines were operating 747-100s: Air France was flying -128 F-BPVB, one of sixteen -128s for the airline, pictured, which was delivered on 25 March 1970; Alitalia; and Iberia. Japan Air Lines (JAL) was the first airline in Asia to take delivery of the 747, with eight -146s. Boeing
(Above) 747-132 N9898 (B-1860) of China Airlines. This aircraft was the ninety-fourth 747 built and was first delivered to Delta on 18 November 1970. It was leased to Pan Am (as Clipper Mandarin) in 1984, and was converted by Boeing in 1986 to 132SCD before being bought by Evergreen International Airlines in 1990. It is still in service with Evergreen. Boeing

(Above) In 1970 United became the first airline to operate the 747 across the Pacific, on its San Francisco–Honolulu service. Pictured with a 1930s Boeing 247 airliner is 747-122 N4703U William M Allen, the fifty-second 747 built, delivered to the airline on 30 June 1970. The aircraft was later leased to Pan Am as Clipper Nautilus, and in September 1988 was converted to a 122/SCD. This 747 is still in service, with Polar Air Cargo (N853FT). Polar was established in June 1993 and began operations with five 747 freighters in July 1994. Boeing

(Below) On 15 January 1971 Braniff introduced the 100th 747 (N601BN) into service, on its Dallas-Fort Worth to Honolulu, Hawaii, route. For a two-year period this single -127 was accumulating flying time faster than any aircraft in the world, with a daily round-trip flight of 7,500 miles (12,000km) between Dallas, Texas, and Honolulu. Daily utilization was fourteen hours, a figure never before attained by the airline industry. Boeing

747-136 G-AWNC City of Belfast, **forty-eighth 747 built, in the British Airways livery of the early 1980s when they dropped the 'Airways', taxiing at London-Heathrow. AWNC was renamed** Lake Windemere **in April 1989, and sold in December 1998. In 1999 it was stored at Chateroux, France.** Ron Green

747-133 CF-TOA, the 104th 747 built and the first of five -133s ordered by Air Canada. This aircraft first flew on 27 January 1971 and was delivered to Air Canada on 11 February 1971. It was broken up in September 1995. Mick Jennings

downturn in international passenger air traffic. Originally, Juan Trippe at Pan Am had based his airline's 747 requirements on the prediction that this would grow by 15 per cent a year, but by 1970, due mainly to a worldwide recession, it was only growing by 1.5 per cent. In November 1970 the US Senate voted against the expenditure of a further $290 million on the Boeing supersonic airliner. On 24 March 1971, when Boeing was more than $1 billion in debt, Congress voted to end the SST project. Thousands of engineers lost their jobs and further pruning at all levels finally reduced the Boeing workforce by two-thirds, from 150,000 to 50,000. Fortunately the US government refunded the $31.6 million development costs Boeing had already paid out on the SST. The sale of the SST mock-up, which had been built at a cost of $12 million, to a Florida promoter, raised another $43,000!

The 'Spacious Age'

Despite the gloomy outlook, one by one many of the national airlines began operation of the 747 on the world's routes. In March 1970, when Boeing production of the 747 peaked at seven aircraft a month, TWA began operating 747-131 (N93102 *City of Paris*, which had been delivered on 31 December 1969) on its New York to Los Angeles service; three years later, in March 1973, it was operating on its New York to London route. Later that same year, TWA began 747-131 operations between the US and Paris and Rome. Also in March 1970 American Airlines began 747 operations on its New York to Los Angeles route using two 747-121 aircraft – *Clipper Rival* and *Clipper Derby* – leased from Pan Am pending delivery of its own aircraft.

The first overseas airline to buy the 747 was Lufthansa, whose first aircraft, 747-130 D-ABYA *Nordrhein-Westfalen* (the twelfth 747 built), first flew on 18 February 1970 and was received on 10 March. The following month D-ABYA entered service on the German national carrier's Frankfurt–New York route, where it replaced 707s. In June 1970 Continental Airlines introduced the 747-124 on its Los Angeles to Honolulu route, and JAL began operations between Tokyo, Hong Kong and Los Angeles. In July 1970 Northwest Orient began 747-151 flights

747-100 Total Production List

C/No	*Series*	*Customer*	*No built*
19637/661	-121	Pan Am	24
19967/678	-131	TWA	12
19725/27	-146	JAL	3
19729/30	-143	Alitalia	2
19733/35	-124	Continental	3
19744/45	-148	Aer Lingus	2
19746/48	-130	Lufthansa	3
19749/52	-128	Air France	4
19753/57	-122	United	5
19761/66	-136	British Airways	6
19778/87	-151	Northwest	10
19875/83	-122	United	9
19896/98	-132	Delta	3
19918/19	-135	National	2
19925/28	-122	United	4
19957/58	-156	Iberia	2
20007	-190	(Alaska Airlines)	not built
2013/15	-133	Air Canada	3
20080/83	-131	TWA	4
20100/109	-123	American	10
20207	-127	Braniff	1
20208	-1D1	Wardair	1
20235	-121	Boeing prototype	1
20246/47	-132	Delta	2
20269/73	-136	British Airways	5
20284	-136	British Airways	1
20305	-1D1	Continental	1
20320/22	-131	TWA	3
20323/26	-123	American	4
20332	-146	JAL	1
20337/39	-147	(Western Airlines)	not built
20347/54	-121	Pan Am	8
20355	-128	Air France	1
20376/78	-128	Air France	3
20390/91	-123	American	2
20401/02	-129	SABENA	2
20528	-146A	JAL	1
20531/32	-146A	JAL	2
20541/43	-128	Air France	3
20708	-136	British Airways	1
20767	-133	Air Canada	1
20798/800	-128	Air France	3
20809/10	-136	British Airways	2
20829	-198	(Air Zaire)	not built
20881	-133	Air Canada	1
20952/53	-136	British Airways	2
20954	-128	Air France	1
21029	-146A	Japan Asia Airlines	1
21141	-128	Air France	1
21213	-136	British Airways	1
			Total: 167

between new York, Chicago, Seattle and Tokyo. United Air Lines became the first to operate the 747-122 over the Pacific, on its San Francisco–Honolulu service.

By the end of 1970 a dozen airlines were operating 747s: Pan Am, American, Continental, Northwest Orient, United, National, and Delta in the US (the last two on domestic routes only), and Lufthansa, Air France, Alitalia, and Iberia in Europe, and Japan Air Lines (JAL) in Asia. On 15 January 1971 Braniff introduced the 100th 747 (-127 N601BN) into service, on its Dallas-Fort Worth to Honolulu route. In November 1970 Eastern Airlines had begun 747 services using *Clipper Constitution* on lease from Pan Am, and in January 1971 also leased this airline's *Clipper Bostonian* and *Clipper Red Jacket*. By the end of 1971 these operators were joined by other, European 747 customers, by Aer Lingus, the Irish national carrier, BOAC, and the Belgian airline SABENA. BOAC had ordered six 747-136s as early as 1966, and the first began scheduled services in April 1971. Five years later BOAC (since 1974, British Airways) had increased its 747-136 fleet to eighteen.

The 'Spacious Age' had indeed arrived.

Last 747-100/-100Bs in Commercial Operation (by airline)

Reg.	*Series*	*Operator*	*C/No*	*Series*	*Operator*
TF-ABW	128	Air Atlanta Iceland	N854FT	122/SCD	Polar Air Cargo
TF-ABG	128	Air Atlanta Iceland	N850FT	122/SCD	Polar Air Cargo
TF-ABO	1D1	Air Atlanta Iceland	N851FT	122/SCD	Polar Air Cargo
C-FTOE	133	Air Canada	N852FT	122/SCD	Polar Air Cargo
C-FTOD	133	Air Canada	N859FT	123F/SCD	Polar Air Cargo
C-FTOC	133	Air Canada	N855FT	124/SCD	Polar Air Cargo
C5-FBS	122	Air Dabia	N858FT	123F/SCD	Polar Air Cargo
F-BPVM	128	Air France	N856FT	132/SCD	Polar Air Cargo
F-BPVP	128	Air France	N857FT	132/SCD	Polar Air Cargo
F-BPVJ	128	Air France	N831FT	121/SCD	Polar Air Cargo
F-BPVL	128	Air France	N832FT	121/SCD	Polar Air Cargo
N703CK	146	American Int Airways	N830FT	121/SCD	Polar Air Cargo
N702CK	146/SCD	American Int Airways	N853FT	122/SCD	Polar Air Cargo
N704CK	146A	American Int Airways	EP-SHC	131/SCD	Saha Air Cargo
N709CK	132/SCD	American Int Airways	EP-SHD	131/SCD	Saha Air Cargo
N3203Y	128/SCD	Arkia/Air Alaska Cargo	N617FF	121/SCD	Tower Air
G-AWNL	136	British Airways	N606FF	136	Tower Air
G-AWNJ	136	British Airways	N604FF	121	Tower Air
G-AWNG	136	British Airways	N603FF	130	Tower Air
G-AWNH	136	British Airways	N602FF	124	Tower Air
G-AWNF	136	British Airways	N608FF	131	Tower Air
G-AWNM	136	British Airways	N53116	131	TWA
G-AWNE	136	British Airways	N4728U	122	United
G-AWNN	136	British Airways	N4729U	122	United
G-AWNP	136	British Airways	N154UA	123	United
G-BBPU	136	British Airways	N156UA	123	United
G-BDPV	136	British Airways	N153UA	123	United
G-AWNO	136	British Airways	N155UA	123	United
F-GKLJ	121	Corse Air Int	N154UA	123	United
4X-AXZ	124/SCD	El Al	N157UA	123	United
N480EV	121/SCD	Evergreen	N691UP	121/SCD	UPS
N481EV	132/SCD	Evergreen	N671UP	123F/SCD	UPS
N479EV	132/SCD	Evergreen	N681UP	121/SCD	UPS
EP-IAM	186B	Iran Air	N676UP	123F/SCD	UPS
JA8143	146B	JAL	N683UP	121/SCD	UPS
JA8142	146B	JAL	N672UP	123F/SCD	UPS
JA8116	146B	JAL	N674UP	123F/SCD	UPS
JA8141	146B	JAL	N673UP	123F/SCD	UPS
JA8115	146A	JAL	N675UP	123F/SCD	UPS
JA8128	146A	Japan Asia Airlines	N677UP	123F/SCD	UPS
5N-ZZZ	148	Kabo Air	N682UP	121/SCD	UPS
			G-VMIA	123	Virgin Atlantic

CHAPTER FOUR

Long Haul

Flights involving 747-100 aircraft have rarely had any serious incidents. In the five years after the first aircraft went into service in January 1970, the 747 had already established itself as probably the safest and most dependable aircraft in airline history. In service with a dozen airlines and with a total of over two million hours in the air, its safety record remained 100 per cent intact. Before the 747, no new aircraft flew as many as 500,000 hours without a fatal accident. Insurance companies, assuming that there would be a crash of some description for every half a million hours of operation, had predicted that 747s would suffer three fatal crashes in the first eighteen months of operation. In actuality, during the first ten years of service, there were five fatal 747 crashes, three of which were pilot error. Besides these, on 6 September 1970, 747-121 N752PA *Clipper Fortune* of Pan Am, en route from Amsterdam to New York, was hijacked by Palestinian terrorists and flown to Cairo where it was blown up on the ground after the passengers and crew had been released. The aircraft had only been delivered to the airline just four months earlier. (A JAL -246B was also destroyed on the ground at Benghazi by terrorist activity in 1973 at the end of a hijack.)

The First 747 Incident in Commercial Service

At San Francisco Airport on the afternoon of 30 July 1971, Pan Am Flight 845-747-121 N747PA *Clipper America* with 199 passengers and eleven crew on board taxied out for the second leg of a flight to Tokyo. The flight had originated in Los Angeles and had stopped in San Francisco before continuing on to Japan. Captain Calvin Y. Dyer (57), who had been a pilot with Pan Am for thirty-two years, and his first officer, Paul Oakes, had already calculated the three critical take-off speeds – V1, VR and V2 – for a departure from runway 28L. (These speeds are used on every aircraft take-off. 'V1 is the 'go' or 'no-go' decision speed. This means that in the event of an emergency occurring before V1, sufficient runway is available for stopping, but after V1 the aircraft is committed to take-off. 'VR' is 'rotation' or lift-off speed, and 'V2' is the safe climb-out speed at which the aircraft can remain airborne and controllable even in the event of an engine failure at V1.) To arrive at these calculations the first officer would have checked the maximum permitted take-off weight of the 747 in the conditions prevailing and using the table for runway 28L with runway length and gradient in mind, and also wind components and temperature.

Having calculated the take-off speeds for 28L, the airport's recorded information service then announced that this runway was unavailable. With runway 28L denied them, Captain Dyer asked for another runway, and after some heated discussion, was given 01R. This runway ends on the bay shoreline, and built out into the water is a long pier with handrails and tall angle-iron gantries, carrying the runway approach lights. The Pan Am dispatcher advised Captain Dyer to 'start at the painted line', and told him that he would have '9,500ft (2,896m) plus clearway ahead of you'. However, the start line of 01R had been moved 1,000ft (305m) so that jet blast did not affect traffic on a freeway nearby, so only 8,500ft (2,591m) was usable. (The 747 needs about 1½ miles (2.8km) of runway to accelerate to its take-off speed.) On the assumption that they would have 10,600ft (3,230m) available for departure on runway 28L, Captain Dyer and his crew had decided to use 10 degrees of flap. This would not be quite enough for a 747 departure from runway 01R. The 'bug' markers on the airspeed indicator (ASI) for the V1, VR and V2 speeds had previously been calculated for runway 28L. Oakes watched his ASI and dutifully called out to the captain as the aircraft went through the V1 and VR speeds. With 10 degrees flap and the power settings employed, the 316 tons of aircraft and payload should have seen the nosewheel lift off at 157 knots (VR). Oakes actually called VR at around 160 knots, because by now the crew could see that they were fast running out of runway. As the ASI registered 165 knots the 747 began ripping through 300ft (90m) of the pier-like structure extending out from the runway over the bay.

A smaller aircraft would not have survived the impact. *Clipper America*, however, was able to climb away even though the steel gantries had ripped through the cabin floor, destroyed the wing flaps, bent the landing gear, and shattered the fuselage bulkheads. Wreckage too was embedded in the tailplane and elevator system. Incredibly no one was killed, mainly because there were few people sitting in the cabin above the wing where the impact occurred. However, one 17ft (5m) long and 2in (5cm) square, light gantry penetrated the cabin, severing the leg of one passenger and crushing the arm of another before exiting through the roof and lodging in the vertical fin. Another piece ripped through three toilets before exiting through the rear of the cabin.

Crucially, the 747's quadruple redundancy prevented total catastrophe. Although three of the hydraulic systems were severed in the impact, the fourth escaped when a 'missile' of angle iron missed it by just 4in (10cm). Captain Dyer was thus able to circle the area for an hour and forty minutes while the crew dumped fuel prior to landing on runway 28L. Fortunately, enough of the undercarriage remained to be able to use the wheels, but the damaged elevators did not work properly and the reverse thrust on three of the engines failed, causing the 747 to veer off the runway. Captain Dyer's skill in saving the aircraft resulted in him and his crew receiving commendations.

747-148 EI-ASJ, the 108th 747 built, was delivered to Aer Lingus, the sixth European airline to receive 747s, on 18 March 1971. EI-ASJ (renamed St Colmcille **in 1981), was last operated by Kabo Air before being stored at Marana, AZ, in September 1997.** Barry Reeve

The First Fatalities

The first loss of passengers in a 747 accident occurred on 20 November 1974 when D-ABYB *Hessen*, a Lufthansa 747-130, crashed shortly after take-off at Embakasi Airport, Nairobi, Kenya, killing fifty-five passengers and four crew of the 157 people on board. The cause was found to be the leading-edge flaps, which had not been extended for take-off. Prior to this, no fewer than eight previous take-offs by 747s of other airlines had resulted in problems with the leading-edge flaps. Each of these incidents was reported to the FAA, who did nothing; neither did the CAA. Fortunately, thanks to the safety margins built into the 747, and to the fact that none of the airports involved was at extreme height above sea level, the lack of leading-edge flaps on take-off was not as critical as it should have been, and all the aircraft involved still managed to get off safely.

In 1972 an incident involving BOAC had resulted in only half the leading-edge flaps on each wing being extended before take-off. Fortunately the 747 had taken off safely, and the fault was later found to be an electric circuit breaker which had been left in the tripped (or off) position after an engineering maintenance check. However, there had been no TOCW ('take-off configuration warning' system) alert, and on further investigation it was found that there was a simple reason for this: incredibly, there was no connection fitted between the TOCW warning device and the leading-edge (LE) flap system. Also, it was found that it was possible for pilots to take off without any of the LE flaps extended, and to receive no warning of this at all because of the way the green warning-light circuits were wired. BOAC warned all its 747 pilots of the need to double-check the flap settings, and the company dutifully notified Boeing, who issued a maintenance service bulletin giving the necessary changes in the LE flap circuit wiring. Unfortunately the bulletin was only ever issued for BOAC and Aer Lingus 747s.

Because the 747's wings, like most large airliners, are slender and lean and provide sufficient lift for optimum cruising speeds of over 500mph (805km/h), they will not normally provide enough speed in the 150mph (240km/h) region – that is during take-off and landing – when lift and low approach speeds, respectively, leave little margin for error. The 747 therefore employs triple-slotted, trailing-edge (TE) flaps on the rear of the wings, while three conventional Krueger flaps are hinged to the leading edge inboard of the inner engine pylon, to provide a total twenty-six LE flaps (thirteen on each side) arranged in sections along the front of the wings. The variable-camber LE flaps fold flat under the wing when not in use, but for landing and take-off they are extended by a clever linkage mechanism which simultaneously 'bends' the fibreglass panels into a curved aerodynamic contour.

Prior to take-off, the TE flaps that extend from the rear of the wings in a downward curve, and the LE flaps, are let out to provide the additional lift that the 747 needs to clear the runway safely. (Used in conjunction, the flaps increase the wing area by as much as 21 per cent, and lift by almost 90 per cent.) When a safe flying speed is attained, the flaps are returned to the inside of the wings, and the aircraft can proceed on its way without incurring any further aerodynamic drag penalty. Pilots have the choice of settings so they can vary the total amount extended; this is so that they can select the correct degree of flap in relation to the weight of the aircraft, the length of runway being used, the weather and altitude conditions, and engine power required for take-off.

On the 747 the TE flaps are driven hydraulically, each of the four systems being pressurized separately to 3,000 psi by a pump mounted on each engine. The LE flaps, on the other hand, are powered by five pneumatic motors driven by bleed air from the engines at up to 45 psi, and operated via torque tubes. (both the TE and the LE flaps can be actuated by back-up electrical motors if required.) Just one lever mounted on the flight deck of 747s controls and harmonizes groupings of both the TE and LE flaps. As soon as the TE flaps are selected and move through 5 degrees, the LE flaps

will deploy automatically. (This sequence was adopted to reduce wing loading and prevent excessive asymmetry in the event of a control-system failure.) If the flaps were not selected for take-off, a green light would illuminate on each pilot's instrument panel, while a separate green light for each of the twenty-six sections on the wings would light up on the flight engineer's panel. In retrospect, mounting the pilots' green light very near the three green lights that confirm that the gear is down and locked, could probably cause the pilot to miss the fact that a light was out. Judging by the number of 747 take-off incidents prior to the Nairobi crash where the aircraft got off the ground without extending the flaps, this must have happened on more than one occasion.

Just before the Nairobi crash, Lufthansa and some other European airlines changed their engine start-up procedures. Previously, Lufthansa required pilots to start their engines while the air valves to the five pneumatic motors were open. Pilots could now start their engines with the LE pneumatic valves closed, their pre-take-off checklist reminding them to turn the valves on again before the flaps were selected. (The TOCW klaxon, which blares out on the flight deck if any item has not been set prior to take-off, was wired to sound as the third engine thrust lever was advanced beyond 50 per cent of its travel.) Because both the TE and LE flaps were activated simultaneously by just the one lever, the TOCW klaxon alert would only sound if the TE flaps were not correctly set – as the LE flaps are set in the same action that sets the TE flaps, there seemed no reason to fit a separate warning device for the LE flaps. However, if the pneumatic valves had *not* been opened after engine start-up, the LE flaps would not have been extended – and because there was no TOCW device linked directly to the LE flaps, no audible warning would have alerted the flight crew to this fact.

So, early in the morning of 20 November, Lufthansa flight 540/19 from Frankfurt taxied out at Nairobi after its short refuelling stop, and prepared to take off for Johannesburg. At the controls for take-off in the right-hand seat was the 35-year-old first officer, Hans-Jochim Schacke. His captain, 53-year-old Christian Krack, would fly the 747 on the last leg of the flight to South Africa. Everything seemed normal on take-off, but as the 747 reached 145 knots (165mph) the aircraft began to buffet and shake. It lost acceleration, and passed only 100ft (305m) above the airport perimeter before it plummeted earthward. D-ABYB's tail struck the ground 3,674ft (1,120m) from the end of the runway, and the 747 bounced and impacted on the ground. Fifty-five passengers and four cabin crew died in the resulting inferno, and another fifty-four people were injured before they could be rescued. Fortunately, eighty-five passengers and thirteen crew survived.

This time the failure to extend the leading-edge flaps on take-off had proved critical because without them the 747 simply could not obtain maximum lift in the thin air at Nairobi Airport (which is 5,327ft (1,624m) above sea level) to become airborne.

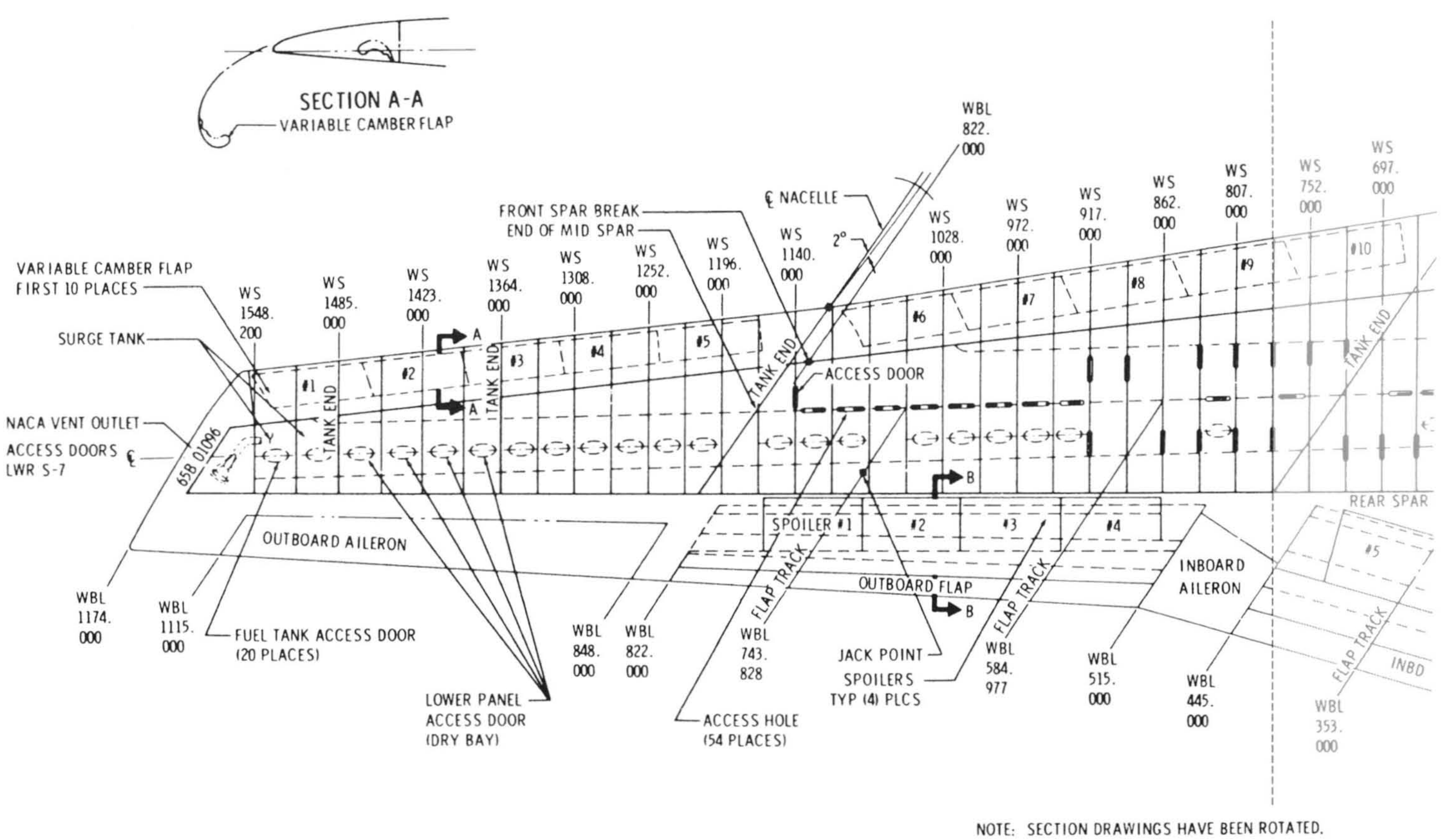
747-148 HS-VGB Doi Suthep **of Air Siam in March 1975, the eighty-fourth 747 built, which first flew on 3 November 1970. It was accepted by Aer Lingus (EI-ASI** St Colmcille **– from 1979,** St Patrick **– on 15 December 1970). It is still in service, with Kabo Air.** GMS

Increasing the Load

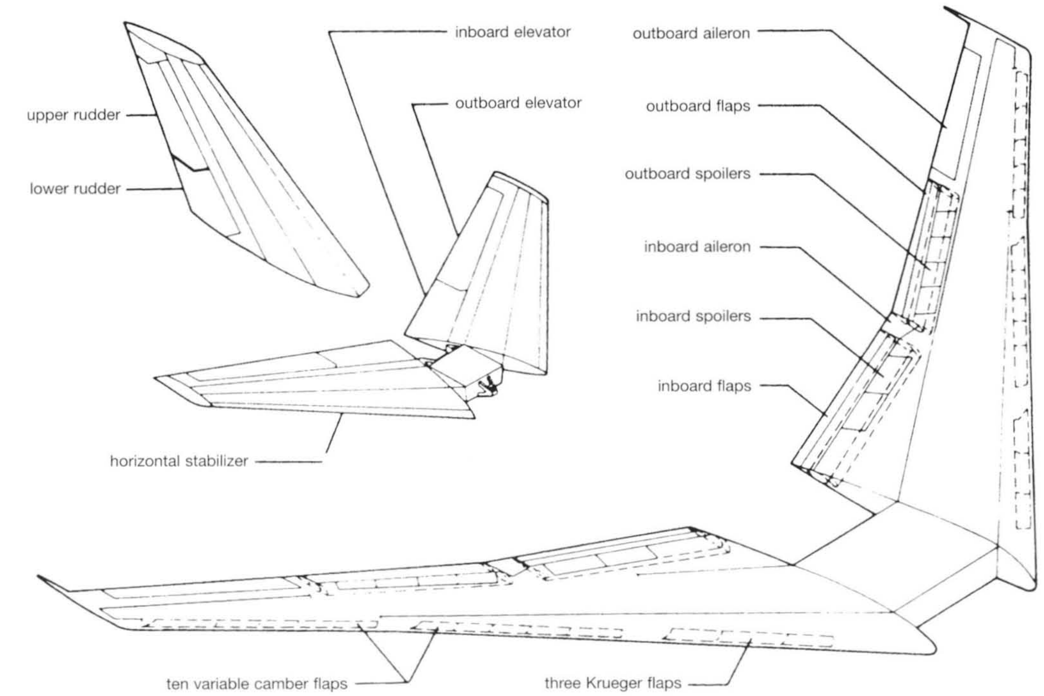
The last of 167 standard 747-100s was delivered on 12 July 1976, but ever since 1968 Boeing had been developing plans for a heavier and more powerful version known initially as the '747B'. A two-phase programme was created for the 747B, whereby Phase A looked to an improved 747-100 weighing 733,000lb (332,490kg), and Phase B, where the weight would rise to 795,000lb (360,610kg). The first phase idea was essential if Boeing were to maintain its 747 momentum with the airlines, although the changes were not as great as those involved in the second phase; in this wholesale structural changes would be made to the aircraft, and more powerful engines would be required than were then available. In Phase B, Boeing would have to increase the span by 24ft (7.3m) to 219ft 8in (67m), and re-engineer the outboard wing structure to move the number one and number four engines further outboard. The bigger wing would deliver greater performance with shorter take-off and better initial cruise altitude, and noise on take-off would be noticeable reduced. Although Phase B represented a major departure from the 747 as first conceived, the incentives were vastly increased passenger and cargo loads on the transatlantic and polar routes.

Phase B relied heavily on a suitable powerplant becoming available, and the Pratt & Whitney JT9D problems which continued to manifest themselves during development of the 747-100 hardly inspired confidence. The 43,500lb- (19,730kg-) thrust JT9D-3A engine which powered the initial production versions of the 747 was simply not powerful enough to lift the heavier versions planned for the 747. By using water-injection, Pratt & Whitney were able to offer a quick-fix solution to the problem of increasing the available thrust on the JT9D-7. This innovation, which had been introduced successfully on piston-engined aircraft in World War II, and more recently on military jets, involved squirting distilled water into the turbines to make the air-fuel mixture expand faster, and lower the operating temperatures. Used in short bursts, the JT9D-3AW produced an additional 1,500lb (680kg) of thrust to increase maximum take-off thrust to 45,000lb (20,400kg) per engine.

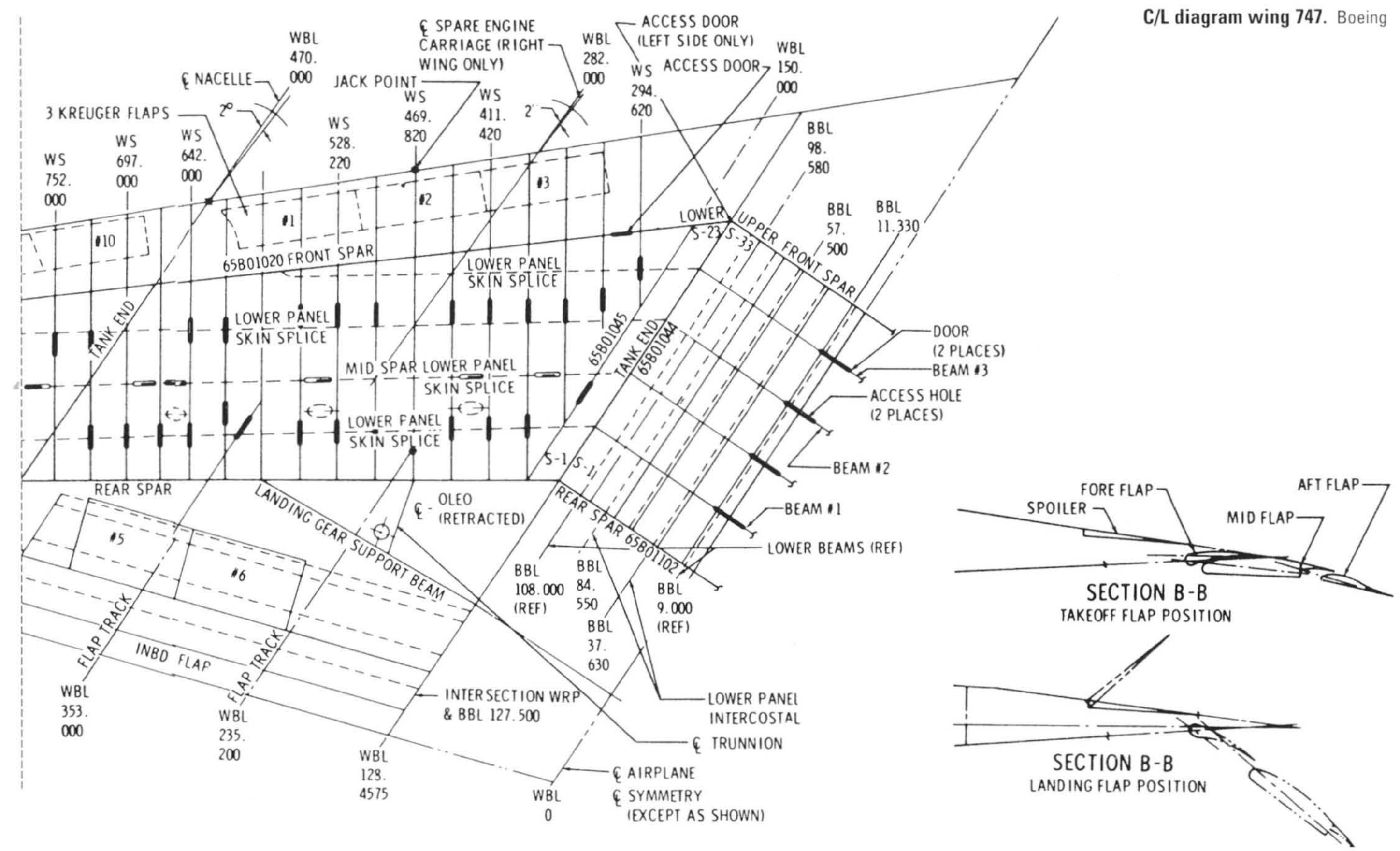
Static 747 tests carried out in February 1970 proved that not only could Phase A still take place, but the possibility of developing the 747B further came with the news that the aircraft weight could in fact be upped to 755,000lb (342,470kg). (This was just as well because amongst other things the static tests revealed that the increased weights meant that the side-of-body wing ribs needed to be strengthened.) Starting in November 1970, all Pan Am's twenty-four remaining 747-121s were returned to Everett to have the new water-injected engines installed. The re-engined aircraft, which during the upgrade also received improved fuel system, flaps, landing gear and doors, were classified as 747-100A by Boeing. Their take-off weight was increased to 755,000lb (342,470kg), as anticipated, which gave an additional 460 miles (286km/h) in range, or a 15 per cent greater payload.

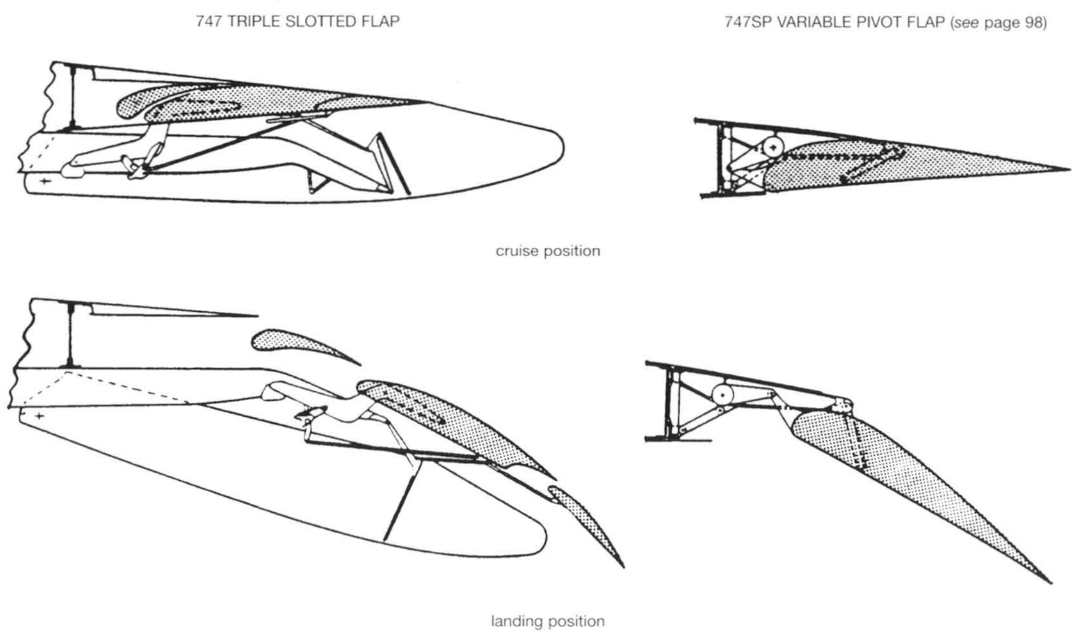


747 wing and tailplane structure showing control surfaces. Boeing



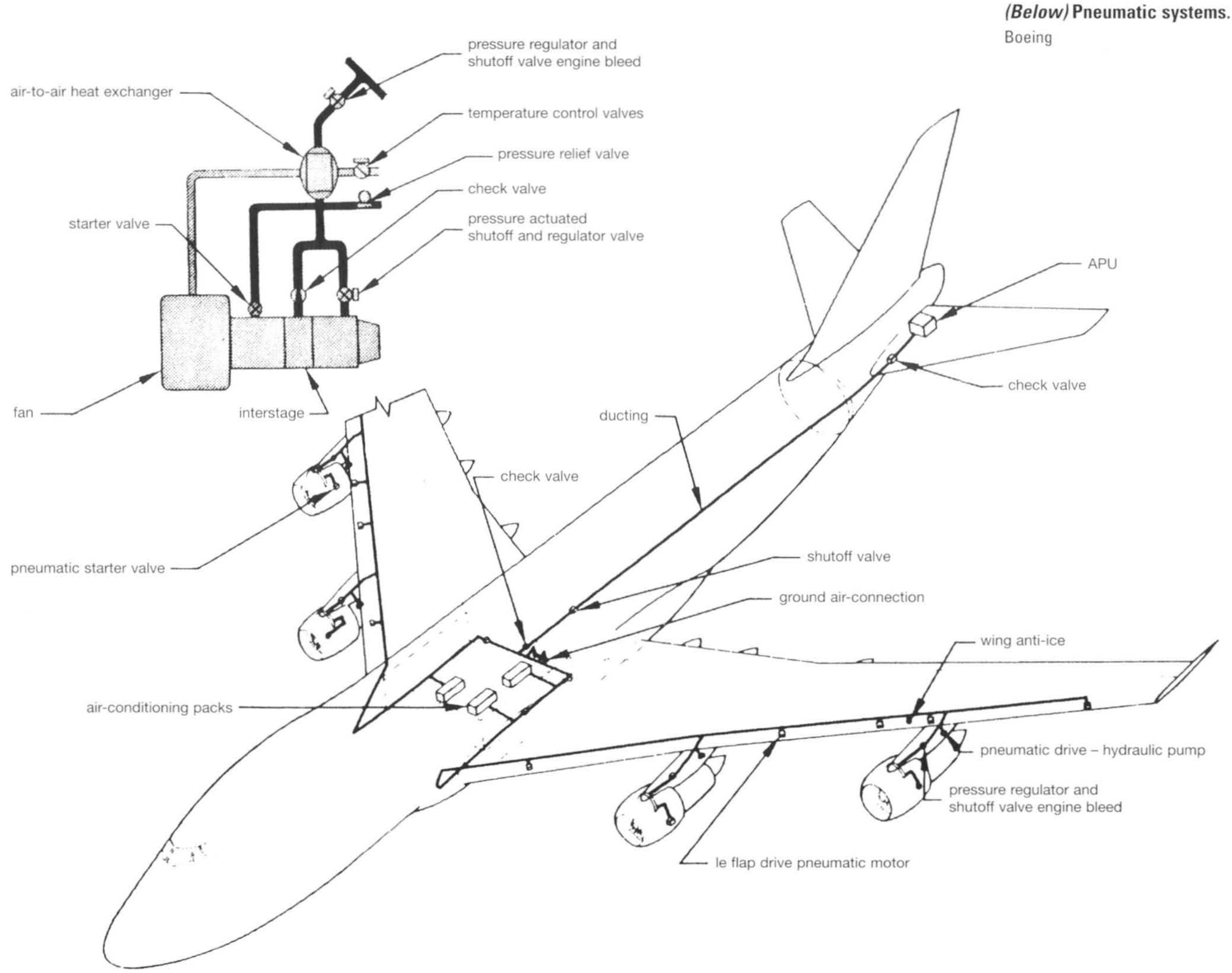
C/L diagram wing 747. Boeing





747 and 747SP trailing edge flap design. Boeing

(*Below*) Pneumatic systems. Boeing



747-121 N743PA Clipper Derby **at London-Heathrow on 21 January 1976. It first flew on 11 March 1970 and was delivered to Pan Am on 28 March 1970. In 1980 it was renamed** Clipper Black Sea, **and was converted to -121SCD in March 1986. It is still in service, with Tower Air.** Graham Dinsdale

Stretching the Possibilities

Boeing, meanwhile, planned to complete the first bigger-winged Phase B passenger version by June 1971, and the first 'super-freighter' version was planned to follow it by February 1972. However, problems with the JT9D became too great, and Phase B never materialized. In April 1973 Boeing looked again at ideas to stretch the baseline -100 series for the short- and long-range routes. Having leap-frogged ahead of the competition and created a completely new market, Boeing had been even more far-sighted when it came to future development of the aircraft. Even with the same basic 747 wing, Boeing were of the opinion that the aircraft could be stretched or expanded to carry up to 1,000 passengers if need be.

Ironically, when they were first offered the huge 747 some airlines had stated that the aircraft was too big for their needs and had wanted it down-sized before they would buy it; but from the outset, the -100 series was planned to be stretched as and when the passenger market demanded it. Convenient 'break'-points at certain sections in the fuselage had been designed in before -100 construction, whereby two fuselage 'plugs', one forward of the wing and one aft, could be inserted in section 42 and between sections 44 and 46, respectively, to lengthen the baseline fuselage by up to as much as 50ft (15m).

In all, Boeing came up with four potential growth proposals, of which two involved stretching the fuselage, one was a double-deck version, and another was a double-deck and stretched configuration. The potential extent of the 'stretch' or enlargement to a double-deck configuration varied depending on whether the aircraft would be used for short-range or long-range operation. The smallest of the stretch options was to insert a 60in (150cm) fuselage plug ahead of the wing, and a 140in (356cm) plug aft of it: on the short-range version this would allow 666 passengers to be carried, and on the long-range version it would permit seating for 472 people. At the same time, Boeing examined the possibility of extending the upper deck in preference to stretching the single-deck areas or adopting a double-deck arrangement. A second stretch option was to insert a 300in (762cm) plug ahead of the wing, and a 140in (356cm) plug aft of it. This combined extension would increase the overall length of the 747 to more than 280ft (85m), allowing 716 passengers to be carried on the short-range version, and up to 544 passengers on the long-range version.

Of the two double-deck designs, one involved extending the upper-deck area to the tail, while the other, much more ambitious proposal, was to employ the same upper-deck stretch and also insert a 160in (406cm) plug forward of the wing, and a 140in (356cm) plug aft of it. The first of these proposals would allow 624 passengers to be carried on the long-range version,

Pan Am 747-121 N737PA Clipper Ocean Herald **(formerly** Clipper Red Jacket**), the thirteenth 747 off the production line, in the early 1980s. This aircraft was last used by IAL Cargo Airlines in 1993 and was broken up early in 1998.** GMS

Pan Am 747-121 N735PA *Clipper Spark of the Ocean* at Heathrow minus some of its number one engine covers. Graham Dinsdale

Several airlines, such as Highland Express, snapped up second-hand 747-100s and -200s. Pictured is 747-123 G-HIHO *Highlander*, which was operated by this airline for a few months in 1987. G-HIHO was repossessed in January 1988, and later leased to Qantas, Air Pacific, Aer Lingus and Virgin Atlantic, as *Miami Maiden* and, from 1992, *Sir Freddie Laker*. This 747-123 first flew on 28 October 1970 (N9669). GMS

By 1976 a total of eighteen 747-136s, powered by P&W JTD9-3/7 turbofans, had been received by British Airways. G-AWNO, the 222nd 747 built, was delivered to BOAC on 7 December 1973. Acquired by the new British Airways on 1 April 1974, it was named *Sir Francis Bacon*. This was changed to *City of Durham* in 1985, and to *Grafham Water* in July 1989. British Airways

and 847 passengers on the short-range version. Stretching the upper deck and adding the two fuselage plugs would create cabin areas on the long-range version for the seating of 732 passengers, and up to 1,000 passengers on the short-range version.

The timing of all these proposals could not have been worse, coinciding as they did with the 1973 oil crisis. And there was the perennial problem of whether engines powerful enough to fly them could be developed successfully. Although none of these proposals actually left the drawing board, they did serve to encourage the later development in stretched upper-deck philosophies, and they also provided added impetus to engine manufacturers in the USA and the United Kingdom.

747-100B

In September 1977, Boeing announced an improved 747-100 with reinforced structure, greater gross weight (753,000lb) (341,560kg), later series Pratt & Whitney JT9D-7 engines, and options for other series of General Electric CF6 and Rolls-Royce RB.211 engines, features already

Two more of British Airways' 747-136s: the nearest is G-AWNE *Sir Francis Drake*, delivered to BOAC on 5 March 1971, then acquired by BA on 1 April 1974. In 1984 *Drake* became *City of Southampton*, and in June 1989, *Derwent Water*. GMS

747-136 G-AWNN, delivered to BOAC on 7 November 1973, and acquired by BA on 1 April 1974. AWNN was first called Sebastian Cabot, **then in 1984** City of Leicester, **and in September 1989,** Loweswater. British Airways

C/N No	*Series*	*Reg*	*Customer*
21759	-186B	EP-IAM	Iran Air
21760	-186B		(Iran Air) not built
21761	-186B		(Iran Air) not built
21762	-186B		(Iran Air) not built
22498	-168B	HZ-AIA	Saudi Arabian Airlines
22499	-168B	HZ-AIB	Saudi Arabian Airlines
22500	-168B	HZ-AIC	Saudi Arabian Airlines
22501	-168B	HZ-AID	Saudi Arabian Airlines
22502	-168B	HZ-AIE	Saudi Arabian Airlines
22747	-168B	HZ-AIG	Saudi Arabian Airlines
22748	-168B	HZ-AIH	Saudi Arabian Airlines
22749	-146B	HZ-AII	Saudi Arabian Airlines

available in the pre-existing Model 747-200B. Pratt & Whitney now offered three new engine options; the 45,500lb-(20,640kg-) thrust JT9D-7, the 46,950lb-(21,300kg-) thrust JT9D-7A, and the 47,900lb- (21,730kg-) thrust JT9D-7W. Rolls-Royce countered with the 51,000lb-(23,130kg-) thrust RB.211-524C fan engine. The first -100B customer was Iran Air, which originally placed an order for four 186B versions, powered by 48,000lb-(21,770kg-) thrust JT9D-7F engines, but three were later cancelled by the airline. The only other customer was Saudi Arabian Airlines, which bought eight 747-168B/146Bs powered by the Rolls-Royce RB.211 fan engine (*see* table left).

In September 1977, Boeing announced an improved 747-100 with reinforced structure, greater gross weight 753,000lb (341,560kg), later series P&W JT9D-7 engines, and options for other series of GE CF6 and RR RB.211 engines, features already available in the pre-existing 747-200B. The first -100B customer was Iran Air, which originally placed an order for four 186B versions, powered by 48,000lb- (21,770kg-) thrust JT9D-7F engines, although three were later cancelled by the airline. EP-IAM, pictured, first flew on 20 June 1979, and was delivered on 2 August 1979. Barry Reeve

In addition to these -100B versions, a further twenty-eight SR versions of the standard -100B, with a strengthened structure, were built for the Japanese home market.

Model 747-100SR

During the late 1960s the domestic air traffic in Japan grew at a phenomenal rate of more than 20 per cent per annum, the majority of passengers being carried on a fleet of 727 and DC-8-61 aircraft. By the end of the decade, when the average domestic load factor had reached 85 per cent, the time was rapidly approaching when the Japanese domestic market would swamp the entire system. All Nippon Airlines (ANA) and Japan Air Lines (JAL) began to look for a solution (ANA would place orders for six Lockheed L-1011 TriStars at the end of October 1972). Boeing, meanwhile, had been busy developing the 747SR, a special

The SR differed from the standard -100B configuration in having a strengthened structure to handle the added stress on the airframe and its systems caused by the greater number of take-offs and landings during a given number of flying hours. Twenty-eight SR-46, -81 and 146B versions were built for the Japanese home market. Boeing

short-range version of the 747-100B, ideal for the high-density, short-haul operations on routes between the Japanese home islands.

The 747SR needed to be able to operate on the 310-mile (500km) Tokyo to Osaka route both ways without having to refuel, but on the longer international routes it would be expected to carry an all-up gross weight of up to 735,000lb (333,400kg), and these figures therefore became the measure which Boeing used as the yardstick for SR performance and specification. At first, Japan Air Lines, the initial customer, had its aircraft arranged to accommodate 498 passengers, including sixteen in the upper lounge, because fewer galley and toilet facilities are required on short flights, but this was later increased to as many as 528 passengers in a two-class layout. Gross weight was reduced to 570,000lb (258,550kg) or (two aircraft only) 610,000lb (276,700kg) by the decrease in required fuel. Take-off weights ranged from 520,000lb (235,870kg) to 735,000lb (333,400kg).

The SR differed from the standard -100B configuration in having a strengthened structure to handle the added stress on the airframe and its systems which would be caused by the greater number of take-offs and landings during a given number of flying hours. (The goal was to give the SR an airframe life capable of 52,000 flights over twenty years of operation, compared to the standard life of a 747 airframe of 24,600 flights over the same period.) The undercarriage and its associated systems, particularly, were strengthened, and so too was almost every component. The fin attachment, stabilizer root, wing lower surface, wing/fuselage splice, middle and rear spars, in-spar ribs, flap supports, spoilers, and all other flying surfaces were strengthened, while crown splices were applied over the centre body. The wing leading edge and engine nacelle struts were also modified.

The first 747SR (SR-46, the 221st 747 built) was rolled out at Everett on 3 August 1973, and flew for the first time on 31 August. Power was provided by P&W JT9D-7s, each capable of 43,500lb (19,730kg) of thrust (all three engine types were available for the 747SR). Registered as JA8117, it received its certification on 26 September 1973 and was handed over to JAL on the same day. JAL began services on its Tokyo–Okinawa route on 7 October 1973. Altogether, JAL received seven SR-46 versions of the 747-100, and three JT9D-powered versions of the 747-100B. These were designated SR-146B. In 1985 JAL ordered two 747-146B SUDs (stretched upper deck); these can seat twenty-five business-class and 538 economy passengers. The first of these aircraft flew on 26 February 1986, being certificated on 24 March, and delivered to JAL on the same day. (In 1987 JAL also took delivery of four short-range (SR) derivatives of the 747-300.)

The first 747SR (SR-81) version for All Nippon Airways (ANA) was JA8133, the 346th 747 built, which first flew on 9 December 1978; it was delivered to ANA on 21 December 1978. The SR-81 version differs from the SR-46 version of the 747-100 in having 46,500lb- (21,092kg-) thrust General Electric CF6-45A engines. Altogether, ANA received seventeen SR-81 versions.

747SR Characteristics with JT9D-7A engines

Maximum taxi gross weight (lb)	523,000	603,000*	713,000*
Maximum brake release gross weight (lb)	520,000	600,000	710,000
Design landing weight (lb)	505,000	525,000	564,000
Zero fuel weight (lb)	475,000	485,000	526,500
Operating weight (lb)	345,000	345,000	345,000
Structural payload (lb)	130,000	140,000	181,000
Cargo/baggage volume (cu ft)	6,190	6,190	6,190

* *options*

Model 747-100/-100B SR

C/No	Series	Reg	Customer
20781	SR-46	JA8117	JAL
20782	SR-46	JA8118	JAL
20783	SR-46	JA8119	JAL
20784	SR-46	JA8120	JAL
20923	SR-46	JA8121	JAL
21030	SR-46	JA8124	JAL
21032	SR-46	JA8125	JAL
21033	SR-46	JA8126	JAL
21604	SR-81	JA8133	Nippon Airways
21605	SR-81	JA8134	Nippon Airways
21606	SR-81	JA8135	Nippon Airways
21922	SR-81	JA8136	Nippon Airways
21923	SR-81	JA8137	Nippon Airways
21924	SR-81	JA8138	Nippon Airways
21925	SR-81	JA8139	Nippon Airways
22291	SR-81	JA8145	Nippon Airways
22292	SR-81	JA8146	Nippon Airways
22293	SR-81	JA8147	Nippon Airways
22294	SR-81	JA8148	Nippon Airways
22594	SR-81	JA8152	Nippon Airways
22595	SR-81	JA8153	Nippon Airways
22709	SR-81	JA8156	Nippon Airways
22710	SR-81	JA8157	Nippon Airways
22711	SR-81	JA8158	Nippon Airways
22712	SR-81	JA8159	Nippon Airways
22066	SR-146B	JA8142	JAL
22067	SR-146B	JA8143	JAL
23150	SR-146B	JA8164	JAL

CHAPTER FIVE

Continuing the Classic Line

747-200 Series

A second variant of the 747, the 747B, later the -200, was announced on 25 November 1967; this was designed to provide greater range. The dimensions of the -200 were similar to the 747-100 and it had the same passenger capacity, but structurally it was strengthened with thicker wing skin and stronger wing stringers, spars, landing gear, beam, flaps and a stronger rib-and-wing-panel splice. The fuselage was made stronger also, with strengthened gear supports, keel beam,

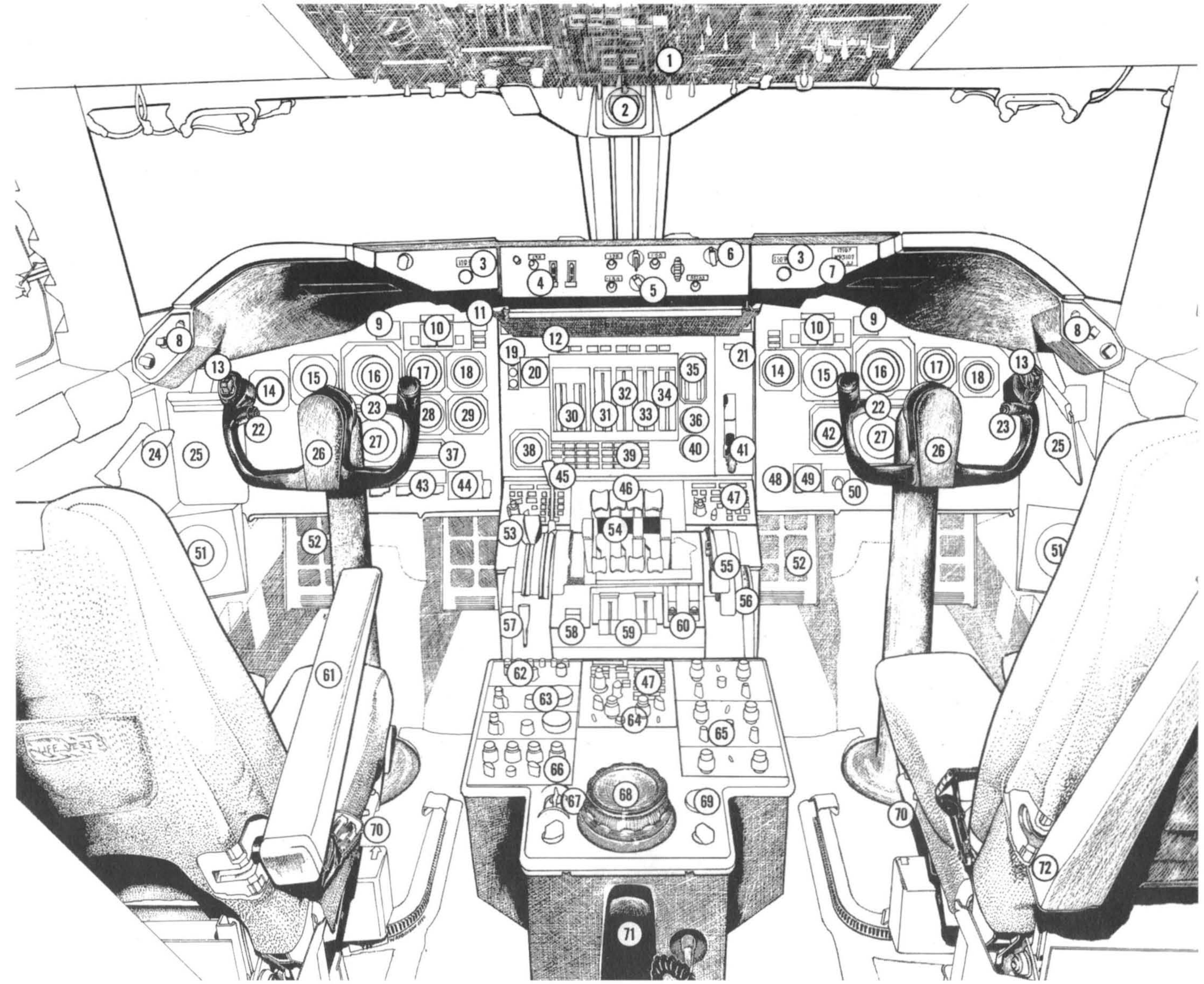
Specification – 747-200B

Powerplant:	Four 54,750lb (24,800kg) Pratt & Whitney JT9D-74R4G2, 52,500lb (23,800kg) General Electric CF6-50E2 or 53,110lb (24,000kg) Rolls-Royce RB211-524D4-B; fuel capacity 47,210–53,160 US gal (178,690–201,210ltr).
Weights:	Empty 374,700–383,600lb (170,000–174,000kg); gross 775,000–833,000lb (352,000–378,000kg).
Dimensions:	Length 231ft 10in (70.65m); height 63ft 5in (19.47m); wingspan 195ft 8in (59.6m); wing area 5,500sq ft (511sq m).
Performance:	Cruising speed 600mph+ (965km/h) Ceiling 40,000ft (12,000m) Range 7,940 miles (12,775km).
Capacity:	Up to 550 passengers.

747-212B N729PA Clipper Wild Wave **of Pan Am at Frankfurt on 23 February 1990. This aircraft first flew on 1 August 1973 and was delivered to Singapore Airlines on 29 August (as 9V-SIB). Pan Am bought the aircraft from Flying Tigers on 24 February 1983 and it was converted to 212BSCD in February 1987. Evergreen International Airlines bought N729PA in December 1989, and this company still uses it in service today.** Graham Dinsdale

747-211B C-GXRD H A Doc Oakes**, the 368th 747 built, and the second -211B for Canadian airline Wardair, being delivered on 25 April 1979 (C-GXRA** Herbert Hollick-Kenyon **had been delivered on 9 June 1978). Both GXRA and GXRD have been used in service by British Caledonian and British Airways (**City of Perth **and** City of Gloucester**), and have been on lease to Philippine Airlines since 1991.** GMS

Condor 747-230B D-ABYF Fritz**, the 128th 747 built, first flew on 17 March 1971 and was delivered on 2 April. It was leased to several carriers, and was then put into storage in the Mojave Desert of California. It was finally broken up in July 1996.** Boeing



Boeing 747-200 control cabin. Boeing

Although considerably larger, the control cabin of a 747 is less complex than that of a 707. The major portion of the instrumentation in a 747 control cabin is identified in this picture of a superjet cockpit:

1 overhead switch panel
2 standby compass
3 navigational radio selector
4 autopilot engage switch
5 navigation mode selector
6 speed mode selector
7 airplane registry no.
8 map, panel light knobs
9 central instrument warning lights
10 approach progress indicators
11 inertial navigation warning lights
12 thrust reverser indicator lights
13 pitch trim controls
14 clock
15 Mach/airspeed indicator
16 gyro horizon
17 electric altimeter
18 radio altimeter
19 navigation marker beacon lights
20 total air temperature
21 gear down/locked indicators
22 microphone switch
23 autopilot disengage
24 nose gear tiller
25 chart holder
26 pilot's control yoke
27 horizontal direction indicator
28 vertical speed indicator
29 standby altimeter
30 engine pressure ratio gauges
31 low speed engine comp.
32 exhaust gas temp.
33 high speed engine compressor RPM
34 fuel flow indicator
35 flap position indicator
36 static air temp.
37 turn and bank indicator
38 flight control position indicator
39 annunciator light panel
40 true airspeed indicator
41 landing gear control handle
42 radio magnetic indicator
43 instrument switches
44 reserve brakes
45 speed brake handle
46 thrust levers
47 inertial navigation controls
48 brake pressure
49 water injection control
50 computer selector switch
51 weather radar scope
52 rudder pedal
53 manual stabilizer trim levers
54 go-around switches
55 flap lever
56 pitch trim
57 parking brake latch
58 parking brake light
59 engine start levers
60 stabilizer trim cutout switches
61 seat arm, down position
62 weather radar control panel
63 automatic direction finder
64 air traffic control transponder
65 very high frequency radio
66 ultra high frequency radio
67 aileron trim
68 rudder trim
69 warning horn silencer
70 seat positioning controls
71 pilot's handset for intercom and passenger announcements
72 seat arm, up position

(Above) **747-257B HB-IGA, the 112th 747 built, which was delivered to Swissair on 29 January 1971 (the second -257B, HB-IGB, was delivered on 25 March 1971). During the years 1982 to 1990, HB-IGA was operated and leased by a number of airlines, including Salenia AB, National, Egyptair and TWA. Landing at London-Gatwick on 7 August 1990 this aircraft (now registered N303TW) suffered fires in numbers two and three engines. After further service, from 1992 until February 1994, it was put into storage at Marana, Arizona.** Swissair

Swissair were to take delivery of two other -257Bs in addition to HB-IGA and HB-IGB, but these were not built. HB-IGB later served with Trans World Airlines, and then from 1994 was stored by the IBA Group at Ardmore, Oklahoma, for parts. Swissair

(Below) **747-2D3B JY-AFB Combi** Princess Haya**, delivered to Alia, The Royal Jordanian Airline, on 11 May 1977, pictured at Houston, Texas, on 8 October 1980. In 1985 in British Caledonian service this aircraft (G-HUGE) was named** Andrew Carnegie–The Scottish American Philanthropist**, and became** City of Exeter **when the airline was taken over in December 1987 by British Airways. This aircraft is currently used by Atlas Air.**
Graham Dinsdale

(Bottom) **Alitalia 747-243BC I-DEML, the 536th 747 built, at JFK Airport, New York, on 4 June 1982. The aircraft is still in service with Alitalia.** via Barry Reeve

747-200B Characteristics with JT9D-7AW engines

Maximum taxi gross weight (lb)	778,000	788,000*
Maximum brake release gross weight (lb)	775,000	785,000
Design landing weight (lb)	564,000	564,000
Zero fuel weight (lb)	526,500	526,000
Operating empty weight (lb)	365,800	365,800
Structural payload (lb)	160,700	160,700
Cargo/baggage volume (cu ft)	6,190	6,190
Fuel capacity: gallons (US)	51,430	51,430
pounds (@6.7lb/gal)	344,580	344,580

** option*

747-212B SX-OAD Olympic Flame**, delivered to Singapore Airlines as 9V-SQI on 2 August 1979, and one of three -212Bs bought from Singapore Airlines by Olympic in 1984–85.** Barry Reeve

747-206B/SUD PH-BUG Orinoco**, one of seventeen -206Bs bought by KLM Royal Dutch Airlines, being delivered on 15 December 1971, landing at London-Heathrow on 12 July 1987. This aircraft now operates with Corse Air International as F-GPJM.** Graham Dinsdale

section 44 bulkheads, skins, stringers, and some door frames. There were changes in the undercarriage design, with all major parts of the landing gear being individually strengthened and fitted with 49 × 17in, 30-ply main and nose-wheel tyres. Brake capacity was increased, too. In the empennage, a strengthened horizontal stabilizer torque box and centre section replaced the earlier tail unit and the trailing-edge flap actuation system, and leading-edge flaps were also improved. Additional fuel was carried in the wing centre section to bring total capacity up to 51,430 US gallons (194,660 litres). All these improvements and upgrades increased the 747-200B's maximum gross take-off weight to 775,000lb (351,540kg).

Originally, power was provided by the Pratt & Whitney JT9D-3AW (water injection) engine, with the water running from tanks at the wing leading-edge root. Later -200Bs were powered by the JT9D-7R4-62 and -7W engines of 54,750lb (24,835kg) thrust, later gross take-off weight increased to 785,000lb (356,070kg) when the 47,670lb- (21,620kg-) thrust JT9D-7A became available in 1973. However, two alternative powerplants were also soon available – the General Electric CF6-50E of 50,100lb (22,725kg) thrust, and the Rolls-Royce RB.211-524-02 of 51,600lb (23,400kg) thrust. The installation of the CF6 engine was tested in the Boeing-owned developmental 747-100, N7470, before being incorporated into production aeroplanes. During testing of the first RB.211 installation, a 747-283B set a new weight record on 1 November 1976, at a gross weight of 840,500lb (381,250kg).

The first 747-200B, a -251B for Northwest Airlines (N611US), the eighty-eighth 747 on the production line, was rolled out at Everett on 30 September 1970. The aircraft flew for the first time on 11 October when it was test-flown to Edwards AFB, in the Mojave desert of California. There, a series of test flights was conducted with the aircraft being loaded with more and more weight, until on 12 November it took off at a maximum take-off weight of 820,700lb (372,270kg). This was some 10 tons heavier than the previous unofficial record take-off weight established by a USAF Lockheed C-5A Galaxy. The 747-200B received FAA certification on 23 December 1970. The first carrier to take delivery of the new model was KLM, which flew the initial -200B (PH-BUA) *Mississippi* to Amsterdam's Schiphol airport on 16 January 1971, entering service the following month. (Northwest received N611US on 26 March 1971.)

The first 200Bs were fitted with three windows on each side of the upper deck as on the -100 series, but the extra weight capacity of the -200 meant that more seating could be installed in this area for first-class passengers, something the airlines were quick to capitalize on. The normal range of a 747-200B with 442 passengers and baggage at a gross weight of 820,000lb (380,150kg) is 6,440 miles (10,360km); ferry range is 7,710 miles (12,405km). 747-238B VH-EBA *City of Canberra* for Qantas, the 147th 747 built and which first flew on 8 July 1971, became the first 747 to have the internally extended upper deck. Although the characteristic 'hump' was externally no different from the -100 series, internally it was extended by 6ft (1.8m) to 25ft (7.5m) in length to seat sixteen people. This 747, delivered to the Australian carrier in July 1971, was also the first to feature a lower-deck galley, reached by an internal elevator system.

747-273C N747WA, the 209th 747 built, first flew on 23 March 1973 and was delivered to World Airways on 27 April 1973; a second -273C, N748WA, was delivered on 25 May 1973, and the third, N749WA, was delivered on 10 June 1974. N747WA was leased to Pan Am, 1974–79, where it was named Clipper Mercury**. World Airways owned the aircraft until 15 October 1983, leasing it out to several airlines. N747WA was bought by Overseas National Airways in November 1983, and it is currently in storage at Evergreen International Airlines at Marana, Arizona. Evergreen still operates N749WA (as N470EV).** Boeing

British Airways placed orders for a Rolls-Royce-powered version of the 747-200, which although dimensionally similar to the earlier P&W-powered -136 variant, operates at much higher gross weights. The first RR-powered -236B flew in 1976, and deliveries of the first of seventeen -236Bs to British Airways (two more were sold to Malaysian Airlines before delivery) began in 1977, the last being delivered in 1988. Five more -200s were acquired by BA in December 1987 when the airline took over British Caledonian, but as these were P&W-powered versions, they were soon disposed of. British Airways

Disaster at Tenerife

Apart from a JAL -200B which was blown up at Benghazi by terrorists at the end of a four-day hijack in July 1973, the early years of -200 operation were trouble free. Then in the late 1970s, 747-200s hit the headlines for all the wrong reasons, and once again in the long history of aviation, it was human error that was to blame. Pan Am had a safety record that was the envy of the airline industry, and the 747 was the safest airliner ever operated by the carrier. In neither of two fatal 747 disasters – the 747-121 ground collision with a KLM 747-206B at Tenerife in March 1977, and the terrorist bombing of Flight 103 in December 1988 – was the 747 or the Pan Am crew held to blame.

On 27 March 1977 Pan Am Flight 1736 from Los Angeles and New York carrying a group of elderly tourists to join a cruise ship, and KLM charter Flight 4805 from Amsterdam, were among the airliners en route to Las Palmas Airport on the Spanish island of Gran Canaria off the west coast of Africa. When a bomb exploded in the passenger terminal at Las Palmas and a warning of a second device was received, all aircraft en route to the island were informed that they would not be able to land there. Captain Jacob van Zantan, a senior KLM training captain, and pilot of PH-BUF *The Rhine*, had to divert to Los Rodeos airport on the neighbouring island of Tenerife, just 50 miles (80km) from Gran Canaria. Victor Grubbs, captain of N7336PA *Clipper Victor* (the same 747-121 that had made the inaugural flight from New York to London-Heathrow on 22 January 1970) asked permission to hold until Las Palmas was available again, but this request was denied and he too made for Los Rodeos, or Tenerife North airport, his alternative destination.

The KLM 747 landed at 13:38 hours that afternoon on Los Rodeos' Runway 30, and *Clipper Victor* touched down thirty-seven minutes later. By now the apron was crowded with diverted airliners, and some were parked on the taxiways. Van Zantan's passengers were disembarked and bussed to the terminal while Pan Am's passengers remained on board. When Las Palmas reopened, Tenerife air traffic control released the Pan Am 747 to continue its journey – but there was an immediate problem, namely that *Clipper Victor*'s path to the take-off runway was blocked because it was parked behind four other airliners, with the KLM 747 nearest of

these, next to the threshold of Runway 12. The other three airliners were a DC-8, a Boeing 737 and a Boeing 727 and being smaller than a 747 they managed to ease past the KLM -206B; but Captain Grubbs and his first officer, Robert Bragg, had to leave the flight deck and measure the distance between the two 747s to see if they could pass safely. They saw that they could not, so reluctantly they agreed that they would have to wait until the KLM 747 taxied out and took off first. This procedure was delayed by an hour and a half because the KLM 747's passengers had to be bussed back out from the terminal, and later, Captain van Zantan decided that he needed to refuel, presumably to save time at Las Palmas before the return flight to Amsterdam. It was therefore evening before the KLM 747 was finally ready for departure.

By this time the weather, which had been fine when the aircraft had first landed, was now turning quite bad, with cloud and fog reducing visibility dramatically, and both aircraft had to rely exclusively on radio communication for their instructions. In the tower, two controllers were on duty and they were using one radio frequency for taxi instructions and the approach frequency for both take-off and approach communications. The KLM 747 received permission to backtrack along the full length of Runway 12 and carry out a 180-degree turn into wind to face the take-off direction. In the meantime, Pan Am 1736 received clearance to backtrack also, and to exit at the third taxiway. The very poor visibility, the radio communication difficulties, as well as fatigue and mounting frustration, all combined to cause confusion, as a result of which the Pan Am crew missed the third exit in the fog bank and carried on to the next exit before leaving the runway.

Captain van Zantan was highly impatient to leave because he knew that if he did not get to Las Palmas and unload his passengers by a certain time, the newly introduced KLM restriction on flying hours would not give him time to return to Amsterdam that day. Much to the consternation of both his first officer and flight engineer, van Zantan opened the throttles and was already rolling down the runway even though they had not received clearance to take off. William Schreuder, the KLM 747 flight engineer, heard the Pan Am 747 communicate with the tower saying that they would confirm when N736PA was clear of the runway, meaning that at this stage it was not. Schreuder queried it with his captain, but van Zantan did not take his hands off the throttles. (Alarmed, Klass Meurs, his first officer, earlier had also queried whether they were clear to take off, but having been equally rebuked, did nothing further.) The KLM 747 was now on a collision course with the Pan Am 747 which was still turning towards the exit and had not yet cleared the runway!

Pandemonium broke out. When the Pan Am crew saw the KLM 747 bearing down on them out of the fog with its landing lights on, Victor Grubbs opened the throttles and tried desperately to swing his aircraft off the runway. Bragg was shouting 'Get off! Get off!' by this time, however, the KLM 747 had reached V1 and was committed to take off. Then the Dutch captain saw the Pan Am 747 in front of him: at this point he was doing 150mph (240km/h) so it was too late for any evasive action – all he could do was pull back sharply on the control column and hope that he had enough height to miss the top of the Pan Am jet. But it was not to be: the KLM 747 collided with the rear fuselage of the Pan Am 747 and sheared off its tail. PH-BUF remained airborne briefly before hitting the runway 500ft (150m) further on, slid for a further 1,000ft (300m), and then exploded.

There were no survivors from the 248 passengers and crew. A further 326 people died instantly in the Pan Am 747, and nine more died later from their injuries. Amazingly, fifty-two passengers and nine crew survived.

Los Rodeos airport, located in the northern part of the island and surrounded by mountains ranging from 6,600ft (2,000m) to 14,500ft (4,400m) was not used by the major airlines after April 1980 when a DAN Air 727 crashed on approach to the airport, killing all 146 passengers and crew. Los Rodeos has since been replaced by a new airport constructed at Reina Sofia on the southern, and much lower reaches of Tenerife.

Down to a Sunless Sea

Multiple redundancy incorporated into aircraft design has proved the difference between safety and catastrophe, and in the very few occasions that the 747 has called on it, rarely have the systems been found wanting. The obvious advantage of a four-engined jet over a two-engined aircraft is, of course, that if one powerplant should fail, then there are three remaining engines to power the aircraft. The statistical chances of two of the engines failing in flight must be remote, for three to fail, even more unlikely, and the eventuality of all four failing – when, if they were not restarted, the aircraft would stay airborne for only about twenty minutes – must be virtually non-existent.

On the night of 24 June 1982 the crew of British Airways' -236B G-BDXH *City of Edinburgh*, under the command of Captain Eric Moody, expected an uneventful five-hour flight from Kuala Lumpur to Perth, Western Australia. G-BDXH, or Speedbird 9, to give its call-sign, had taken off laden with 247 passengers and 200,620lb (91,000kg) of fuel for the flight. The night was moonless but clear, the flying conditions were smooth and the en route weather forecast was good. The flight crew sat down to a meal after settling into the cruise at 37,000ft (11,280m). In the right-hand seat beside Moody was his senior first officer, Roger Greaves, and behind sat Sn Eng Off Barry Townley-Freeman. The crew had finished their meal by the time the 747 was south of Jakarta on Airway B69.

Moody had a quick look at the area ahead of the aircraft with the weather radar and picked up nothing more interesting than returns from the surface of the sea. He made his way aft, and descended the stairs to the first class area; he had just started a conversion with the forward purser Sarah Delene Lead when he was called back to the flight deck by Fiona Wright, the first stewardess. As he climbed the stairs he noticed puffs of 'smoke' billowing out from the vents at floor level, and a smell which he described as 'acrid, or ionized electrical', such as one finds near sparks from electrical machinery. He entered the flight deck to find the windscreens ablaze with what appeared to be the most intense display of St Elmo's fire he had ever experienced. Moody strapped himself into his seat and again looked at the weather radar. Nothing of significance was in view, but he was pleased that in his absence, the other two crew members had put on the seat-belt signs and the engine igniters.

Roger Greaves then pointed out of the side windows at the engine intakes, which were glowing as if lit from within. The electrical discharges had a stroboscopic effect, and this gave the illusion that the fans were moving slowly backwards. At the same time the St Elmo's fire on the

***(Above)* British Airways' 747-236B G-BDXH** City of Edinburgh **at London-Heathrow in October 1988 prior to its departure to Sydney and Brisbane, Australia. On the night of 24 June 1982, BDXH – or 'Speedbird 9' as it was coded – under the command of Capt Eric Moody, experienced an eventful flight from Kuala Lumpur to Perth, western Australia, when it lost all four engines while overflying Java.** Author

The flight crew of City of Edinburgh**, 24 June 1982: (left to right) S.F.O. Roger Greaves, Capt Eric Moody and S.E.O. Barry Townley-Freeman.** Eric and Pat Moody Collection

windscreen had given way to a display of what looked like tracer bullets. All this happened so quickly that there was little time for discussion, besides which Moody had his attention on what he considered to be the most important problem, the smoke which appeared to have got into the air-conditioning.

Before he could speak, Barry Townley-Freeman called out, 'Engine failure number four!' Moody immediately asked for the Engine Fire Drill, and the other two crew members carried it out. Greaves believes the crew were helped by the fact that the problem compounded itself gradually, the feeling of the danger they were all in building up only slowly so they avoided the trauma of being plunged all at once into an extreme situation. They became more alert and concentrated as the incident became more complex and at no time lost control of their reasoning processes. However, they were soon forced to face the full consequences of their problem by the voice of the flight engineer:

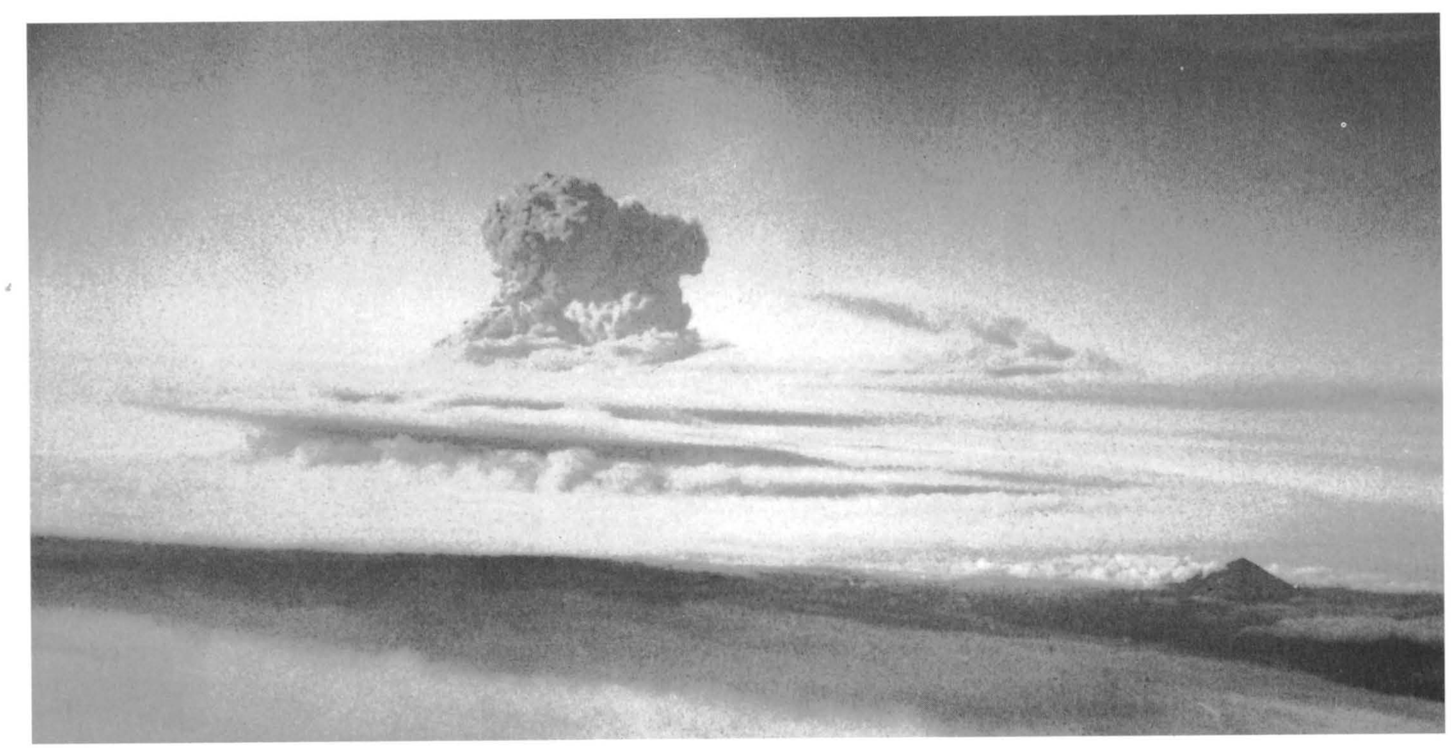
> 'Engine failure number two ....?'
> 'Three's gone! ...'
> 'They've all gone!'

Moody stared at the instrumentation in front of him and refused to accept the full impact of what had been said. He had practised a four-engine failure drill on the simulator some months earlier, but then the assumption had been that all the generators would fail, leaving the aircraft on standby electrical power, fed from the aircraft batteries. This would have caused a failure of the co-pilot's instrumentation and much of the cockpit lighting – yet the former all appeared to work, and the autopilot remained in control. The display on the engine instruments was also very confusing as these were a mixture of Smiths and General Electric, some of which froze under the power loss, and some whose needles dropped off the scale. There were also some amber lights indicating that the engines had exceeded their maximum gas temperatures. While he studied this confusion, Moody heard Townley-Freeman suggest that he shut the engines down; at the same time he noticed that the airspeed was decreasing. He put the autopilot into a gentle descent and turned to his co-pilot with the instruction: 'OK Roger, put out a Mayday.'

> 13.44 'Jakarta, Jakarta, Mayday, Mayday Speedbird 9. We've lost all four engines. We're leaving 370 [37,000ft]'

Moody then controlled the aircraft using the autopilot, while the other two carried out appropriate emergency drills. Both pilots shared the task of moving the engine start-levers on different occasions. Because the autopilot remained in control Moody had time to consider the likely cause of such a multiple failure and what he might do about it: electrical? (check all circuit breakers); fuel? (turn on all pumps and cross-feed cocks); icing? (turn on the engine anti-icing). The first relights were attempted on engines one, two and three, but Moody decided, with the agreement of the crew, to attempt relights on the number four engine along with the others. (The number four engine fire-handle had been pulled when the fire drill had been carried out.)

At 26,000ft (7,925m) the cabin pressure warning horn sounded as the cabin climbed through 10,000ft (3,048m). The crew started to don their oxygen masks – although when Greaves removed his mask from the stowage it fell to pieces in his hand: the bayonet fitting came out of the supply pipe and the tubing disengaged itself from the mask. As a result, Moody was presented with an unenviable choice. Should he continue to descend as slowly as possible and have his co-pilot suffer the effects of anoxia, or should he increase the rate of descent until the aircraft was at a more survivable altitude? He chose the latter, and began an emergency descent.



Mount Galunggung erupting. L.J.R. Allen ANZ

He decided not to extend the gear as instructed in the flying manual, however, because he knew he might have to ditch the aircraft with gear extended, should it prove impossible to retract them. With hindsight it is now obvious that during gear extension, hydraulic power from windmilling engines might not be powerful enough to move the gear *and* the flying controls at the same time. They had previously turned the aircraft on a northerly heading back towards Jakarta, and they decided that with a safety height of 10,500ft (3,200m) in that area, they would turn back out to sea when the aircraft reached 12,000ft (3,660m). At this time, the inertial navigation systems were giving a display of gibberish and were no use in fixing their exact position. When they reached 20,000ft (6,100m) Moody retracted the flight spoilers and reduced the rate of descent. He noticed that Roger Greaves ironically had by then managed to fit his oxygen mask together.

At this point Greaves noticed that his airspeed indication showed 320 knots whilst Moody's showed 270 knots. Moody thought that it was worth assuming that the higher figure was correct in case they had been attempting to start the engines while outside the relight envelope. Again they had no luck – although the fuel had been igniting behind the engines and treating those passengers with window seats a view of what appeared to be four engines on fire. At about that time the cabin reached 14,000ft (4,270m) and the passenger oxygen masks were deployed. Moody decided it was time to have a word with them:

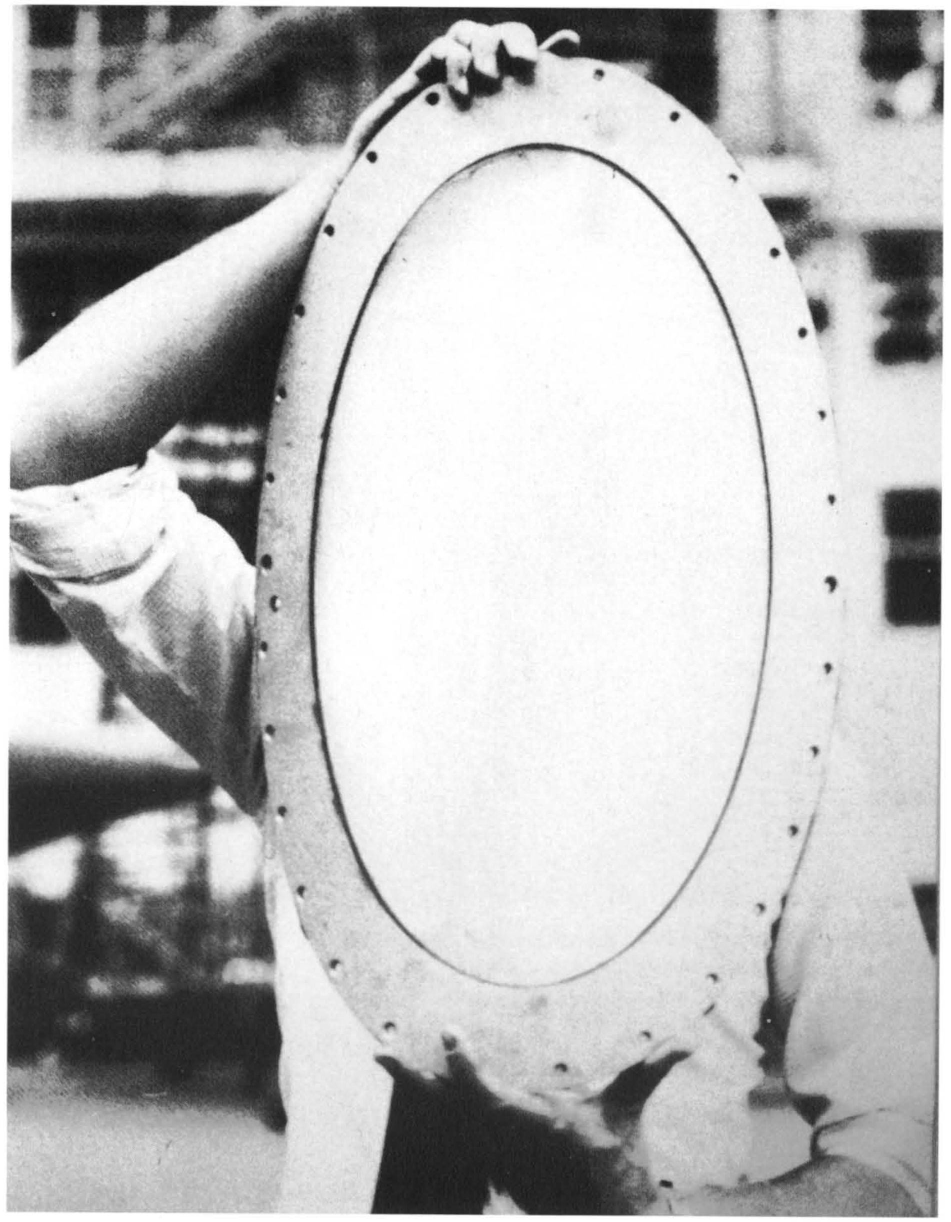
> 'Good evening, ladies and gentlemen: this is your captain speaking. We have a small problem in that all four engines have stopped. We are doing our very best to get them going again. I trust you are not in too much distress.'

Moody then asked the cabin service officer to come to the flight deck, and attempted to explain the problem to him while wearing his oxygen mask. Graham Skinner could not understand Moody's words, but he realized that his presence on the flight deck was not helping matters, so he nodded and returned to his job of helping the passengers.

It was at about this point that Moody started to consider the awesome consequence of attempting a deadstick touchdown on the sea at night. His father had taken him, as a child, to Hythe pier to watch the flying boats land, and had learned that flying boats did not fly at night because of the difficulty in judging height above water. He remembered, with some amusement, a training film made by British Airways which simulated a ditching at sea. The captain playing the role – and he was an authentic captain, not an actor – had used the phrase: 'it's not our day!' in passing the bad news to the cabin crew. This reverie was interrupted by sounds of jubilation from the other two crew members as number four engine started. (This was the engine which had first run down, and the success amply repaid Moody's gamble in trying to start it.) The other three engines started, an almost interminable ninety seconds later. They were at 12,000ft (3,600m).

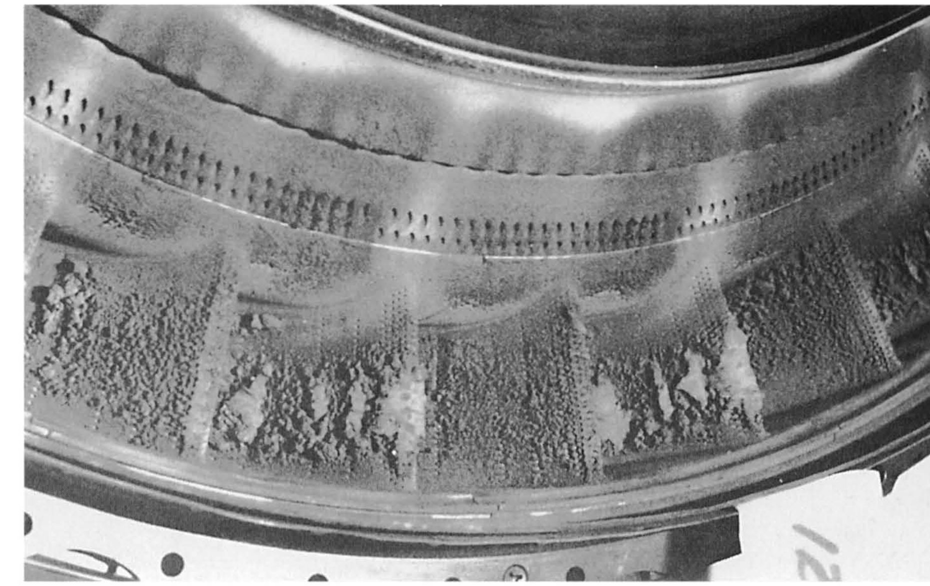
> 13.57 'Speedbird 9: we're back in business! All four running, level 12,000.'

They immediately requested a climb to a height which gave them more clearance over the high ground ahead of them, and asked for clearance to Jakarta. They



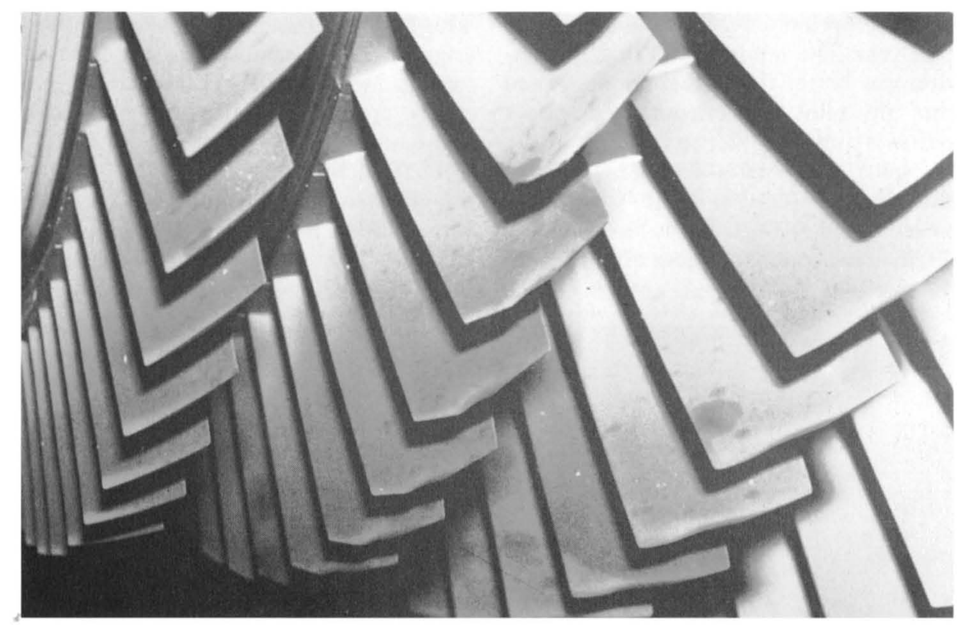
The effect of sandblasting on the landing light cover. Eric and Pat Moody Collection

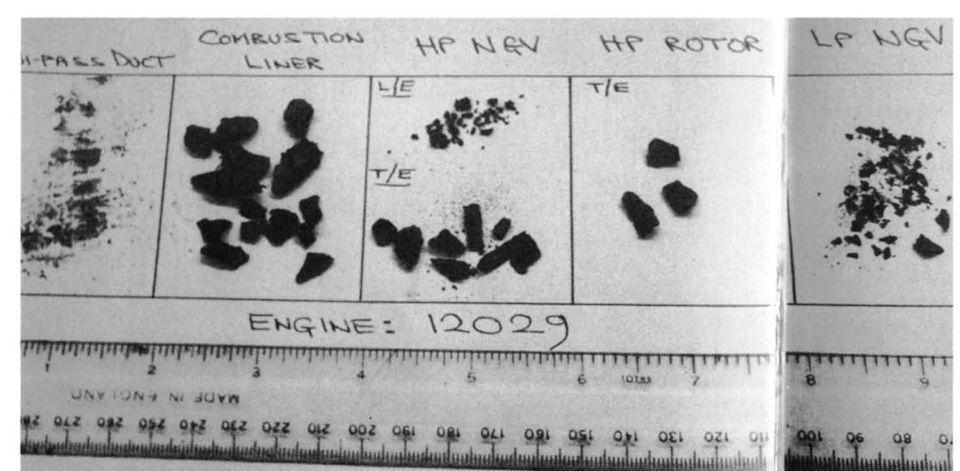
***(Right)* Fused volcanic ash on the high-pressure nozzle guide vane of number two engine.** Eric and Pat Moody Collection



***(Below)* The effect of erosion on IP, numbers 1, 2, 3 and 4 rotor blades.** Eric and Pat Moody Collection

***(Bottom)* Samples of volcanic ash taken from number three engine.** Eric and Pat Moody Collection





climbed to 15,000ft (4,570m) – and at about this height ran into St Elmo's fire again. When the throttles were pulled back to level out, the number two engine surged continually. It felt as though it would shake the aircraft apart, so it was shut down, but not without great reluctance. At this point Moody suspected that St Elmo's fire, above 15,000ft (4,570m), was somehow connected with the engine problems and concluded that the engines themselves were severely damaged. He decided to descend to get away from the strange atmospheric effects, although he resolved to leave the throttles in their present position and to control the aircraft speed and descent by the use of speedbrakes, flaps and undercarriage. This required a leap of the imagination, because up until then they had all had strong suspicions that the engines had failed because of an oversight or an error by the crew. They were cleared to Jakarta airport where the weather was fine, with calm wind and good visibility. The only added complication was that glidepath information was not available for Runway 24.

> 14.21 'This is Speedbird 9, could you turn runway lights fully up please.'

While the aircraft was on the base leg for Runway 24 the crew had great difficulty in picking up any lights on the ground, and in particular in picking out the runway lights. Eventually the runway was spotted to the right of the aircraft, out of the co-pilot's side window. When they lined up with the

runway the lights again disappeared and immediately the crew realized that their front windows were almost opaque. The final descent to touch down was made using the localizer to stay on the centre-line, and by peering through the outer edge of the left-hand front window, which was still clear. Moody was just able to make out the lights of the visual approach slope indicators (VASIs) on the left of the runway. The other two crew members called out the radio altitude and DMF distance to help in judging the descent. When they were over the runway the entire front window area was filled with a diffuse glare of light. This was comforting in that it proclaimed the general proximity of the runway, but the delay before the wheels touched down felt like minutes rather than seconds. The landing itself was smooth. Moody felt that the earth seemed to gather them up: downstairs in the cabin spontaneous cheers and clapping broke out from the passengers.

The crew taxied the aircraft off the runway towards the terminal building. The glare of light from the parking area again filled the front windows with a blinding glare. They decided to call it a day, and parked the aircraft.

> 14.31 'Speedbird 9. I can't see with the light in my eyes. I'll hold it.'

It was two days before the crew received any explanation of the incident. Barry Townley-Freeman was convinced that it was caused by an encounter with volcanic ash when he found his hands and clothes covered in a fine black dust as they waited for the steps to be brought to the aircraft. And indeed, he was right, because when they got inside they found that all the leading edges, engine nacelles and nose-cone were stripped of paint as if the aircraft had been sandblasted – as in one sense it had: it transpired that they had flown into the dust cloud from a volcanic eruption from Mount Galunggung, on the west of the island of Java, and 110 miles (177m) south-east of Jakarta. (While cumulo-nimbus thunderclouds and the like show up on aircraft weather radar screens, volcanic dust does not because the radar will only register echoes from water droplets contained in thick cloud, rain, snow and hail. The plume of ash started to become visible on satellite weather photographs, after the event.)

The engines were the worst affected parts of the aircraft, with the turbine blades having sustained the most damage: the tips of the blades were ground away where they had been blasted by the ash at high speed. The material of the ash was mostly silicate particles, with a mean diameter of .075mm. Quite apart from wearing away the high-speed parts of the engine, the 'silicacious refractory material sintered in contact with the hot metal, fusing itself to the blades'. This is what happens inside steel furnaces. The changes in blade shape and size had serious effects on the efficiency of the engines, with the number four engine (significantly the engine which ran down first) being the least damaged. Ash was also found in the pitot tubes which had caused the differing airspeed readings.

In October 1984, ICAO issued a special report on the dangers of volcanic ash to aircraft, where it was pointed out that the incident on 24 June 1982 was the ninth eruption of Mount Galunggung that year. The report found that prevention was better than cure, but suggested that any pilot who encountered such a problem should, altitude permitting, reduce thrust to zero, descend and leave the area as soon as possible. Consideration should be given to turning off engines and restarting them when clear of the ash and inside the relight envelope of the aircraft.

No warning about the danger from volcanic eruption had been issued to the crew at the pre-flight weather briefing before their departure from Kuala Lumpur – and information about the eruption in the 'Notices to Airmen' (or NOTAMS) was conspicuous by its absence. Nor had air traffic alerted the crew by radio, while they were en route, of any significant or hazardous changes in the weather (SIGMENTS). In fact volcanic hazard was only entered into the NOTAM network the following afternoon, long after Speedbird 9 had landed, and even then it was not timed or dated, which makes the information suspect at worst! In view of the lack of ready data, it is probably not surprising that almost three weeks later a Singapore Airlines 747 was allowed to fly into the same area and the volcano was still active. This time the dust cloud put three of the engines out of action, but the captain managed to land safely at Jakarta.

The crew of *City of Edinburgh* – which was renamed *City of Elgin* in July 1989 – were fêted by the world's press and the television media, and Moody in particular was praised for his coolness and professionalism in averting a near-disaster.

The flight and cabin crew of City of Edinburgh **after their ordeal.**
Eric and Pat Moody Collection

Air India 747-237B VT-EFO Emperor Kanishka**, one of eleven -237Bs purchased by the airline, delivered on 30 June 1978. This aircraft was lost over the Atlantic Ocean off the Irish coast on 23 June 1985 while en route from Montreal to London, with the loss of all 307 passengers and twenty-two crew.** Boeing

Off Course to Disaster

On 18 November 1980, a Korean Air -2B5B crashed at Seoul airport on approach. Then on 1 September 1983, HL7442, a -230B formerly owned by German carrier Condor, became the second 747-200 Korean Air to be lost: it had strayed hundreds of miles from its intended route and was shot down into the Okhotsk Sea near Sakhalin Island by a Soviet fighter, with the loss of all 269 passengers and crew. Once the misguided theory that the Korean Air 747 was on a spying mission over Soviet territory had been quashed, the more logical and probable reasons for the aircraft straying from its intended flight plan were put forward. The most likely cause for this centred on the 747's navigation system.

Captain Chun Byung In and his crew had taken over KAL 007, with 246 passengers on board, at Anchorage, Alaska, on 31 August for the onward flight to Seoul. (The aircraft had earlier been flown to Anchorage from New York by another crew.) Captain Chun and his crew would have begun their checks, including programming the three inertial navigation systems (INS) (the multiple redundancy used on the 747 means that if a fault develops in one of the INS systems, another takes over). INS provides an exact position for the aircraft by detecting the rotation of the earth from a gyroscopically stabilized platform, and permits a crew to read their exact position in degrees and minutes of latitude and longitude throughout a flight. After the INS is switched on, the aircraft must remain stationary for twenty minutes to allow the gyros to stabilize. The INS can also be connected to the autopilot to create a completely automated navigation system which forms the integral part of the flight management system (FMS).

Before their departure from Anchorage at 05:00 hours local time, the INS would have been programmed to follow Route R20 out over the Bering Sea and north Pacific, and all the waypoints (INS locations) along the route entered in. It could be that the INS had been incorrectly programmed. Alternatively, after take-off and the direct clearance to Bethel on the Alaskan coast, the captain may have turned the aircraft using the auto-pilot control heading knob and forgotten to switch it back to INS later, an oversight which would leave the 747 to continue flying on a magnetic compass heading (when the INS is not connected the aircraft is guided by its magnetic compass). The magnetic compass setting overrides the instructions from the INS, but the crew would be warned of this – the three green lights showing that the INS was connected would simply not have been lit. Also, the distance-to-go meter would not have counted down to zero as the 747 passed each waypoint, and instead would have registered many miles north of track. (Just before each waypoint an amber light shows on the INS to warn the crew, and so they can send a time and position on VHF). The automatic direction finder (ADF) would also show the anomaly.

If left unchecked, with the INS unconnected, and the magnetic compass affected by wind drift and magnetic variations, the 747 would simply be led away from its intended course. Whatever the reasons, before KA007 had left Alaskan airspace it was already 12 miles (19km) north of its intended course, and by the time they were well into the flight they were 150 miles (240km) north of their correct course: on this heading, the 747 would end up flying over highly sensitive Soviet territory on the Kamchatka peninsula.

Around the same time that the Korean Air 747 overflew the Kamchatka peninsula, a USAF RC-135 intelligence-gathering aircraft was in the same general area, and it may be that the Soviet defence system mistook the airliner for the spy plane. In any event, shortly before the errant 747 crossed into international waters again, Soviet fighters were ordered to intercept it. Unaware that they were 200 miles (320km) off track and heading into mortal danger, Captain Chun and his crew carried on towards Sakhalin Island,

P&W JT9D-7F-powered 747-238BL VH-EBA *City of Canberra*, the first of twelve -238BLs bought by Qantas, being delivered to the Australian airline on 30 July 1971. This aircraft, the 147th 747 built, is now operated by Aerolineas Argentinas (LV-WYT). Qantas

747-267B VR-HKG, the 385th 747 built, one of eight -267Bs bought by Cathay Pacific, being delivered on 20 July 1979. It still serves the airline, as B-HKG. Boeing

747-124 HK-2000 (N747AV) *Eldorado* on lease to Avianca (Aerovias Nacionales de Columbia), 1976–82. This aircraft first flew on 2 July 1970 and was delivered to Continental Air Lines on 13 July. It is currently operated by Tower Air. Boeing

Philippine Airlines' 747-2F6B touching down. Boeing

pursued by three Soviet fighters. One of the Soviet pilots got to within visual range and reported that he could see his target's navigation lights. There was no attempt made to call the airliner. The Soviet fighter pilot fired two Anab radar-guided missiles, which destroyed the tail and knocked off one of the engines, and the 747 spiralled down into the sea.

Two years later, in October 1985, the captain of a JAL 747 flying from Tokyo to Paris strayed over Soviet territory after flying around some turbulence and forgetting to re-engage the NAV mode of the INS. Fortunately, this time the Soviets did not send up their fighters to shoot down the airliner: contact was eventually established between the 747 and the ground, and the airliner was allowed to continue.

747-300 Series

In order to meet the insatiable appetite of the airlines for a 747 with extra payload and range, Boeing carried out a long study of possible stretches to increase the passenger capacity of the 747-200 series. By 1976 they were actively looking to stretch the -200B fuselage by 25ft (7.5m), to extend the overall length to about 256ft (78m). At the same time they looked to lengthen the upper deck to station 1000 over the wing, the hump being faired into the body of the main deck almost back to station 1241, or almost as far back as the wing trailing edge (this was a much longer extension than on any previous upper deck design studies). The proposed fuselage extension would mean inserting a 140in (356cm) plug at fuselage station 741.10 ahead of the wing root (but would not have extended into the upper deck), and one 160in (406cm) plug aft of the wing root.

The proposed 25ft (7.5m) fuselage extension never left the drawing board, but the proposal to extend the upper deck did at least offer some possibilities in the development of the -300 series. On 11 June 1980 Boeing finally came up with the stretched upper deck (SUD) version of the 747. Swissair's interest at the drawing-board stage in July that year was the driving force behind Boeing's decision to go ahead with production of the new -300 series. By giving the all-important launch order for four (later five) 747-357s – two all-passenger versions and three Combis – Swissair played a crucial role in getting the new aircraft series off the ground. These -300s are used on Swissair's North Atlantic and Far East routes,

Specification – 747-300

Powerplant:	Four 54,750lb (24,800kg) Pratt & Whitney JT9D-74R4G4, 55,640lb (25,240kg) General Electric CF6-80C2B1 or 53,000lb (24,000kg) Rolls-Royce RB211-524D4.
Weights:	Empty 383,400–393,500lb (173,900–178,500kg); gross 775,000–833,000lb (351,500–377,900kg).
Dimensions:	Length 231ft 10in (70.65m); height 63ft 5in (19.50m); wingspan 195ft 8in (59.6m); wing area 5,500sq ft (511sq m).
Performance:	Cruising speed 619mph (996km/h) Ceiling 45,000ft (13,700m) Range 6,502 miles (10,500km).
Capacity:	496 passengers (typical), 563 (maximum).

747-2B5B N1798B first flew on 16 April 1973 and was delivered to Korean Air Lines (as HL-7410), on 1 May 1973. This aircraft is still in service with this airline, registered HL-7463. Boeing

747-2B5B HL-7410 of Korean Air Lines carrying a fifth engine under the port wing. Boeing

747-2B3BC F-BTDG, the 518th 747 built, first flew on 1 April 1981, and was accepted by French carrier UTA (Union de Transports Ariens), on 23 April, this aircraft was converted to 2B3M/EUD in March 1986 for Air France. Boeing

and on services to other long-haul destinations at certain times of the year.

Boeing engineers extended the hump further aft by 23ft 4in (7m 10cm) to seat about forty-four more passengers than the standard -200B. This new arrangement would provide for up to ninety-one tourist-class passengers or thirty-eight business-class passengers in the upper deck; the latter was also given two larger exits and additional windows. Changes were made to the main cabin, too: by placing five pairs of wider type A exits on the main deck, and replacing the mid-stairway with a new straight stairway that led upwards to the aft section of the upper deck, passenger seating could be increased to 550. Swissair's -357s can accommodate eighteen passengers in both standard and Combi versions in all-slumberette layout. Business-class seating is provided to the rear of first class and on the upper deck, offering a total of sixty-six seats. It is in economy class that the two versions differ: the economy class of the all-passenger version has 304 seats, giving a total capacity of 388 passengers. The Combi version seats 181 in economy, for a total capacity of 265.

The increased length of the upper deck upped the empty weight of the -300 by about 10,000lb (4,640kg) compared with the -200B, limiting range to 6,440 statute miles (10,360km) with 452 passengers and luggage. This was largely offset by the aerodynamically refined contouring of the upper deck extension which reduced drag and increased the typical top cruise speed from Mach 0.84 to 0.85. Swissair's -357s can land in category 3A conditions of minimum visibility, a decision height of just 20ft (6m) and runway visual range of a mere 500ft (150m).

'Big Tops'

At first the new aircraft was offered as a SUD, or extended upper deck (EUD), version of the -200B and was launched with an order for four from Swissair. The airline already had a 747 on order (Line No.570/HB-1GC) and this was to be stretched on the production line. It finally emerged as a 357M, the SUD/EUD being re-designated the 747-300 series. The first 747-300, a 3B3 version (Line No.573/F-GDUA) for French airline UTA (Union de Transportes Aeriens), was rolled out on 15 September 1982 and made its first flight on 5 October. Flight-testing began with two different engines, the JT9D-7R462 on 5 October 1982, and the CF6-50E2 on 10 December. F-GDUA flew for the first time on 10 December 1982 and was delivered on 1 March 1983. (F-GDUA was badly

Pan Am 747-212B/SCD N726PA Clipper Cathay **at LHR, November 1990, carrying a fifth engine. N726PA was accepted by Singapore Airlines (9V-SQD) on 6 February 1975. It was bought by Boeing on 28 June 1983, and leased to Cargolux, and Kabo Air; it was then bought by Pan Am on 8 June 1984. It is still in service, as N808MC, with Atlas/Arrow Air.** Graham Dinsdale

***(Above)* 747-200s for Qantas, Alitalia, and Air France, moving down the final assembly line on their own undercarriage.** Boeing

On 11 June 1980, Boeing had drawn up plans for the stretched upper deck (SUD) version of the 747 to seat about forty-four more passengers than the standard -200B. The first 747-300 (N6967B), a 3B3 version for French airline UTA (F-GDUA), was rolled out on 15 September 1982; the aircraft made its first flight on 10 December 1982, and was delivered on 1 March 1983. F-GDUA was destroyed by fire at Paris-Charles de Gaulle, on 16 March 1985 (pictured). Tony Hudson

(Opposite page, top) **At Everett the completed 747s are taxied across the highway bridge at night (so as not to distract drivers) to the paint shop for painting in their respective airline liveries. Typically it takes up to four days and 560 man hours to paint a 747. These freshly painted 747-200s and -300s were pictured at Seattle in 1989.** Author

(Opposite page, bottom) **Swissair gave Boeing the all-important launch order for four (later five) 747-357s: two all-passenger versions and three -357BC Combis. On 6 March 1983 Swissair took delivery of HB-IGC, a Combi, its first -357BC, and the 570th 747 built. HB-IGC entered service on 28 March. Swissair's 747-357s are used on the airline's North Atlantic and Far East routes, and on services to other long-haul destinations at certain times of the year.** Boeing

(This page, top) **747-329M 00-SGC flew for the first time on 29 May 1986 (N6005C), and was accepted by SABENA Belgian World Airlines on 10 June 1986.** Boeing

(This page, above) **747-312M 9V-SKP first flew (N6005C) on 16 January 1987 and was delivered to Singapore Airlines on 20 March. All SIA 747-200 and -300 series have the logo 'Big Top' emblazoned on the forward upper fuselage. 9V-SKP is pictured landing at Schiphol Airport, Amsterdam, on 14 April 1988.** Graham Dinsdale

damaged by fire during maintenance at Paris-Charles de Gaulle Airport on 16 March 1985 and had to be scrapped.) On 5 March 1983 Swissair took delivery of HB-IGD *Basel-Stadt*, a -357 Combi, and HB-IGC *Bern* followed, on 19 March. Swissair began 747-300 services on 28 March.

Altogether, twenty-one Combi versions of the -300 were sold; however, no freighter versions were ordered. Sales of the -300 series generally were disappointing, with sixty all-passenger versions bought by Air France, Cathay Pacific, Egyptair, KLM, Korean Air, Malaysian, Qantas, SAA, SABENA, Saudia and Singapore (the first of fourteen was delivered to the latter in April 1983, and all have been dubbed 'Big Tops').

Production of the -300 series ended in 1990, the last aircraft being delivered to SABENA. With eighty-one -300 series being sold, the situation was disconcerting for Boeing, to say the least, because sales of the 747 had entered a downward trend for the previous eight years in succession. In September 1982, when the first -300 was rolled out, the 747 production rate at Everett had slowed to less than two a month, down from seven 747s a month just two years before. The order book for 1983 was even worse, with production dropping to an all-time low of just one 747 per month. However the work force could still be kept relatively busy, as existing 747-200 models could undergo the extended upper deck modification. In October 1983, not only did KLM agree to buy its second -306, it also placed a contract with Boeing to have ten of its GE CF6-50E2-powered -206B/Combis converted to SUDs.

This work was extensive, and involved removing half of the upper fuselage as far back as the leading edge of the wing, and replacing it by three new upper fuselage sections. It also added two emergency escape doors and slides. The first KLM -206B – PH-BUP *Ganges*, a Combi – arrived back at Everett late in 1984 and was completed in December that year. The other nine KLM -206s – one -206B and eight Combis – returned to Everett during 1985; the last of these (PH-BUT *Admiral Richard E Byrd*) was flown back to the Netherlands in March 1986.

In 1986 Boeing also modified two GE-powered -2B3B Combis with upper decks for UTA of France, and built two new short-range 146 SUD versions for JAL. The first of these was JA8190 (designated 747-100B SR/SUD), which first flew on 26 February 1986 and was delivered on 24 March that year. The second, JA8176, made its delivery flight on 29 August 1986. These brought the number of SUD versions build to ninety-five. This total includes four 747-346SR short-range derivatives of the 747-300 for JAL, powered by P&W 54,000lb- (250,030kg-) thrust JT9D-7RG2 engines, capable of carrying 563 passengers. JA8183, JA8184, JA8186 and JA8187 were delivered to JAL in 1987–88. The first aircraft (JA8183) flew on 24 November 1987 and was delivered to JAL on 10 December.

747-306M PH-BUW, which first flew on 20 September 1986 (N6055X), was the last of three -306Ms for KLM Royal Dutch Airlines; it was delivered on 3 October 1986, and was named Leonardo da Vinci **seven days later. It is pictured taking off from Schiphol on 14 November 1987.** Graham Dinsdale

747-341 PP-VNH, one of five -341s for Varig (Viaçao Aérea Rio-Grandense), which first flew on 22 November 1985; it was delivered to the Brazilian airline on 10 December that year. Boeing

747-344 ZS-SAT, the second of two -344s (the other is ZS-SAU) which first flew on 27 March 1983, and which was delivered to South African Airways (SAA) on 2 May that year. Boeing

747-368 HZ-AIO, one of ten Rolls-Royce RB.211-powered -368s for Saudi Arabian Airlines, 1985–86, landing at London-Heathrow on 12 July 1987. Graham Dinsdale

747-3B5 HL-7468, the first of three -3B5s for Korean Air. This aircraft was written off on 6 August 1997 when it crashed in hills on approach to Agana, Guam. Boeing

CHAPTER SIX

Baby Boeings

In 1971 the Lockheed L-1011 TriStar and the McDonnell Douglas DC-10 were introduced on continental US routes and the short-to-medium-haul sectors throughout the world. These two first-generation widebody trijets were not really designed for long haul, but were aimed at the middle market situated between Boeing's 169-seat 707 and the 380-seat 747. McDonnell Douglas began developing its intercontinental DC-10-30 and -40 models, and the following year these were certificated. Lockheed meanwhile went ahead with plans for an extended-range L-1011. In the L-1011 and DC-10, Lockheed and McDonnell Douglas between them saw an opportunity to replace the ageing fleets of 707-320s and DC-8-60s on the short- and medium-haul routes. The arrival of their competitors' first-generation trijets was not lost on Boeing or the airline industry as a whole. Boeing knew it had to compete in this arena, and quickly, or their customers would buy trijets, but with no off-the-shelf design in sight, what could the company offer?

Initially, Boeing looked to a long-range version of its 200-seat 7X7 (*see* Chapter 12), but this design was only available on paper and the airlines would hardly wait for the aircraft to be developed when Lockheed and McDonnell Douglas trijets were readily available. Also, Boeing would be hard pressed to justify an all-new design with its attendant high development costs. Boeing therefore looked to the 747 with a view to shortening it and possibly deleting two of the wing-mounted engines and installing the third in the tail, thereby creating its own trijet design. Although this concept was received in certain places with incredulity, the idea was not without merit. A short-bodied derivative of the 747 had to be a better and less costly option than a whole new design, and commonality with existing models in service would prove to be a bonus for the carriers concerned.

Apart from anything else, operational and maintenance costs, spares, and also

Boeing shortened the 747 fuselage by 48ft 4in (14.7m) to 176ft 9in (54m) to create the 747SP 'Special Performance', or 'Baby Boeing' as it is nicknamed. Left is N247SP, the first SP and the fourth off the production line, which flew for the first time on 14 August 1975. Certification of the SP by the FAA was made on 4 February 1976. On 17 May 1976 N247SP, now N531PA Clipper Liberty, later Clipper Freedom, was delivered to Pan Am, the largest SP operator, with ten SP-21s. All of these were acquired by United Airlines on 22 April 1986 when Pan Am agreed to sell its Pacific Division to United. (Pan Am folded on 4 December 1991.) N531PA Clipper Freedom was finally withdrawn from service in July 1994. Right is N347SP (N532PA) Clipper Constitution, which first flew on 10 October 1975 and was delivered to Pan Am on 29 March 1976. In the middle is SP-86 EP-IAA Fars, the first of four SP-86s for Iran Air, delivered on 12 March 1976. Behind are 747-200s for British Airways and Aerolineas Argentinas, and an SP-44, one of six for SAA. Boeing

crew-training expenses would be minimal compared with the introduction of an all-new aircraft. Even so, it all boiled down to the age-old problem of seat-per-mile costs. Also, Boeing would have to produce a design that would deliver lower aircraft-per-mile costs than that of the 747-200B: that is, the cost in dollars of operating an aircraft on a per-mile basis as a breakdown of airframe, engine and equipment costs, crew expenses, fuel burned, and so on. Put more simply, the Boeing design would have to be faster, more economical, longer ranging, and capable of carrying a bigger payload, than either the L-1011 or the DC-10-30/40.

One of the ways of saving weight would have been to remove the fourth engine from the 747 wing and mount two on one side, the third on the other. Another, more conventional proposal, was to bury the number two engine in the root of the tail-fin as in the 727 configuration. This was not unlike the 747-3 preliminary design which Boeing had rushed through in 1968 in an abortive attempt to head off sales of DC-10s to Northwest Orient. But whatever way one worked it, removing an engine from the wing meant that the wing itself would have to be completely redesigned to take into account the different stress and loading characteristics, and all the advantages of flexibility and lightness would be lost. Keeping it simple therefore, the designers finally opted to retain the four engines and original wing, while creating a short-bodied fuselage.

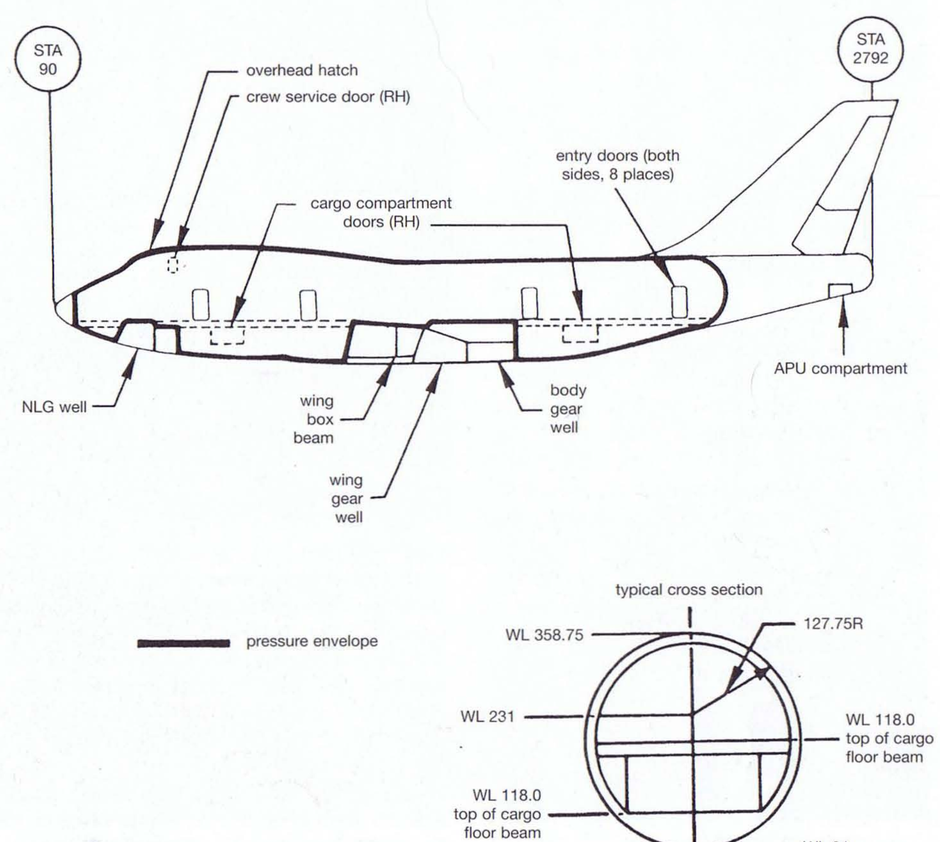
The 747 Special Performance

Early in 1973 the short-bodied 747 project took on added urgency with the news that long-standing and valued Boeing customer Pan Am was looking to place an order for new aircraft on its short-to medium-haul routes. Moreover the rumours were that the DC-10-30/40 or -30SB was the leading contender. Lockheed, predictably, countered with their L-1011 TriStar, but although the California company failed in its sales pitch, it later sold Pan Am a fleet of long-range, short-bodied TriStar 500s. Joe Sutter and his team were convinced that the four-engined 747 short-body – or 747SB – was the answer to the competition, although initially the Boeing management, and Pan Am, were not so sure. (Pan Am dubbed the SB 'Sutter's Balloon', which led to the project being changed to 'SP' for 'Special Performance'.) Boeing sized the 747SP to carry 281 mixed-class passengers (the 747-100s and -200Bs carried 385 passengers).

In August 1973 it was predicted that 214 747SPs could be sold during 1976–85, producing a net increase in 747 sales of 183 aircraft and a total sales revenue of $5.9 billion. Equally importantly, it was estimated that the SP would replace only thirty-one anticipated 'conventional' 747s and that McDonnell Douglas would lose potential sales of 149 DC-10-30/40s valued at $4.8 billion. It was considered that the main US customer for the SP would be Pan Am, with twenty aircraft, while overseas, JAL, El Al and Qantas would account for a further twenty-eight SPs. Total SP sales during 1976–78 were expected to be around 85–143 aircraft. At the beginning of September 1973 Boeing decided to put the SP into production, and late that same month Pan Am, now convinced of the benefits of the SP over its rivals, placed a firm order for ten 747SPs valued at $280 million (including spares and an option for fifteen more SPs) with deliveries to begin in 1976.

Specification – 747-200SP

Powerplant:	Four 43,500–53,000lb (19,700–24,000kg) Pratt & Whitney JT9D, 52,500lb (23,800kg) General Electric CF6-50E or 50,100lb (22,700kg) Rolls-Royce RB211-524B; fuel capacity 47,210–53,160 US gal (178,690–201,211ltr).
Weights:	Gross 660,000–690,000lb (299,000–313,000kg).
Dimensions:	Length 184ft 9in (56.3m); height 65ft 5in (19.9m); wingspan 195ft 8in (59.6m); wing area 5,500sq ft (511sq m).
Performance:	Cruising speed 619mph (995km/h) Ceiling 45,000ft (13,700m) Range 10,222 miles (16,400km).
Capacity:	305 passengers and 20,000lb (9,100kg) cargo.



747SP body diagram.

(Top) **N7470, the first of the breed, rolled out on Monday 30 September 1968, resplendent in white with a red stripe down the window line, and the logos of the twenty-six launch airline customers adorning the nose.** Boeing

(Above) **N747PA** Clipper America, **the second 747-100 built, was rolled out at Everett on 28 February 1969, and flew for the first time on 11 April. It was delivered to Pan Am on 3 October 1970. In 1973** Clipper America **was leased to Air Zaire, as** Mont Floyo, **before returning to Pan Am service in 1975.** Clipper America **was renamed** Clipper Sea Lark **in 1980, and renamed again in 1981 as** Clipper Juan Trippe. Boeing

747-237B VT-EBD Emperor Ashoka **first flew on 8 March 1971, and was delivered to Air India on 22 March. On 1 January 1978 the aircraft crashed into the Arabian Sea after take-off from Bombay.** Boeing

Northwest 747-200 at London-Gatwick, 16 February 1992. Graham Dinsdale

(Below) 747-243BC Combi I-DEMC Taormina first flew on 14 November 1980 and was delivered to Alitalia on 26 November 1980. Boeing

(Bottom) 747-228F F-BPVR (N17838), which first flew on 28 September 1976, one of seven -228Fs purchased for Air France Cargo, being delivered on 13 October 1976. In Air France service 747 freighters are known as 'Pelicans', a reference to the upward-opening nose door. Boeing

(Above) 747-243M Combi N516MC of Atlas Air at Kai Tak, Hong Kong, 12 February 1996. This aircraft was delivered to Alitalia as I-DEMD Cortina d'Ampezzo on 12 December 1980. Graham Dinsdale

747-270C YI-AGO Euphrates of Iraqi Airways at Frankfurt on 6 February 1989. This aircraft was delivered to Iraqi Airways on 17 August 1986. It was put into storage at Tunis, Algeria, in February 1991. Graham Dinsdale

(Below) 747-124 HK-2000 (N747AV) Eldorado on lease to Avianca (Aerovias Nacionales de Colombia), 1976–82. This aircraft first flew on 2 July 1970 and was delivered to Continental Air Lines on 13 July. It is currently operated by Tower Air. Boeing

(Above) **747-243B G-VGIN** Scarlet Lady **of Virgin Atlantic, the 134th 747 built and which was first delivered to Alitalia (as I-DEMU** Geo Chavez**) on 7 May 1971. It has also served with National, Malaysian and CAA of China.** Sgt Jack Pritchard RAF PR

An SP and 747-300s for JAL under construction at Seattle in 1989. Author
***(Right)* The wing assembly for a 747 is manoeuvred over the top of 42 section fuselage sub-assemblies at Seattle, 1989.** Author

(Below) **747-267B VR-HIB at Kai Tak, Hong Kong, on 30 April 1998. It first flew on 30 June 1980, and was delivered to Cathay Pacific on 16 July 1980.** Graham Dinsdale

(Top) **Cathay Pacific 747-367 at Kai Tak, Hong Kong, 14 May 1990.** Graham Dinsdale
(Middle) **Swissair 747-357 lifting off at Zurich in August 1998. Swissair was launch customer for the -300, taking delivery of its first -357BC, a Combi, on 6 March 1983.** Graham Dinsdale
(Bottom) **SP-B5 HL7457 on finals at Kai Tak, 27 June 1997. It first flew on 30 January 1980 and was delivered to Korean Air on 18 March 1981.** Graham Dinsdale

(Top) Ansett Australia 747-312 VH-INJ in the eye-catching Sydney 2000 scheme, landing at Kai Tak on 29 April 1988. This aircraft first flew on 11 November 1983 and was delivered to Singapore Airlines on 22 November. Graham Dinsdale

(Above) Outgoing Cathay 747-367 VR-HOL appears to leap-frog China Airlines Cargo 747-209F B-1864 at Kai Tak, 29 April 1998. Graham Dinsdale

Singapore Airlines' 'Megatop' (747-412 9V-SMJ) coming in to land at Kai Tak in 1996. Graham Dinsdale

(Above) Rolls-Royce RB211.524G-powered Air New Zealand 747-419 ZK-NBT at Frankfurt, 24 May 1997. The flight time from Auckland to Frankfurt, with a stopover at Los Angeles, is 24 hours 25 minutes. Graham Dinsdale

(Below) British Airways' 747-436 G-BNLR Rendezvous being fitted out at Marshall Aerospace, Cambridge. In 1998 Marshalls undertook work on thirty-two BA aircraft: this involved installing all seating, also in-flight entertainment equipment, a mezzanine floor for the crew rest area, and other interior changes to BA specification. In February 1999 Marshalls completed the first World Traveller modification, which provides individual TV screens in the seat backs of economy class seats. MoC

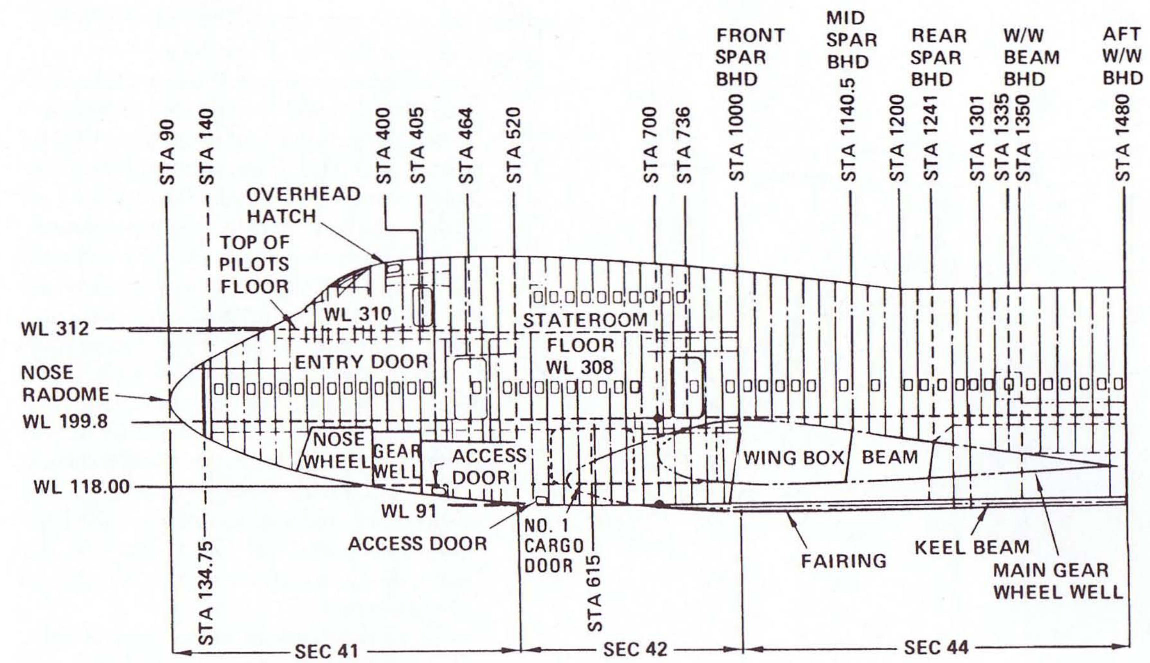
(Above) A beautiful view of a 747-400 banking on finals to Kai Tak Airport, Hong Kong, June 1997. Graham Dinsdale

Air France 747-428 F-GEXA (advertising the World Cup Finals with a different footballer on each side of the cabin) taxiing at Kai Tak, Hong Kong, in April 1998. Graham Dinsdale

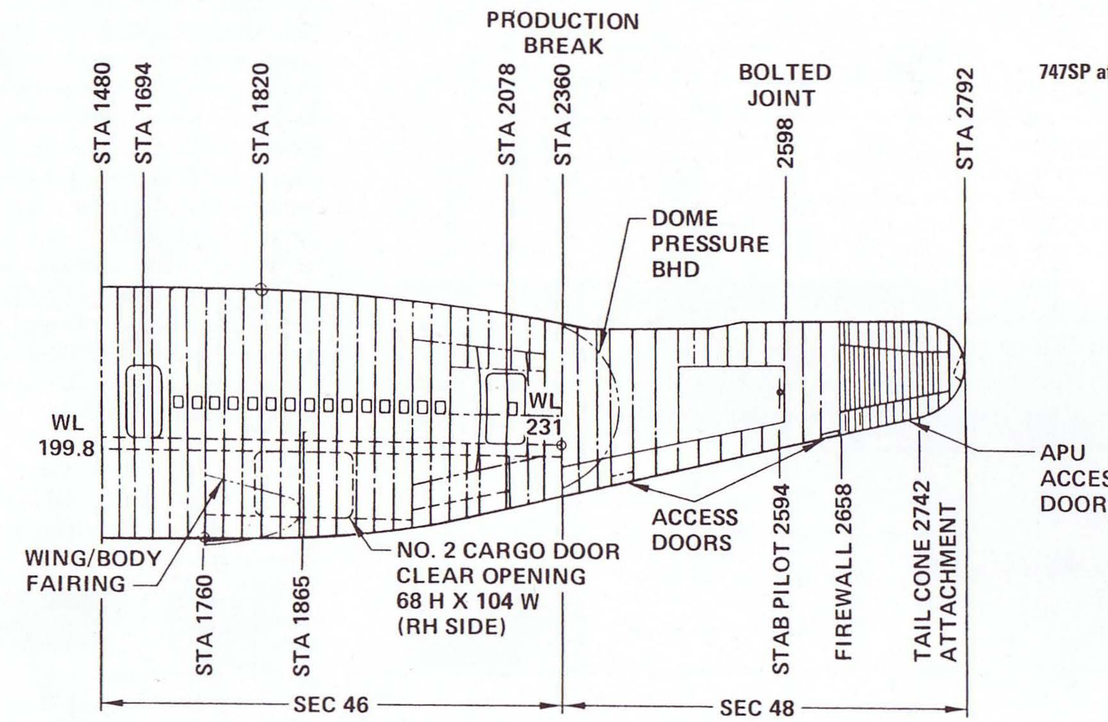
(Above) **747-436 G-BNLC, formerly** City of Cardiff, **and** City of St Andrews, **now in 'Dove' scheme.** John Dibbs

747-406 PH-BFM Mexico City **of KLM Asia banking past Checkerboard Hill.** Graham Dinsdale

(Below) **Snr 1st Off Alan Emery of British Airways does his walk-round check of 747-436 G-CIVM** Nami Tsuru, **or Speedbird 2018, before the departure from Denver, Colorado, for London-Gatwick. The swirling design in blue and grey on the tail is a traditional Japanese art form known as 'Nihon Ga'; the original painting on which the design is based is entitled 'Waves and Cranes'.** Author



747SP forward body diagram.

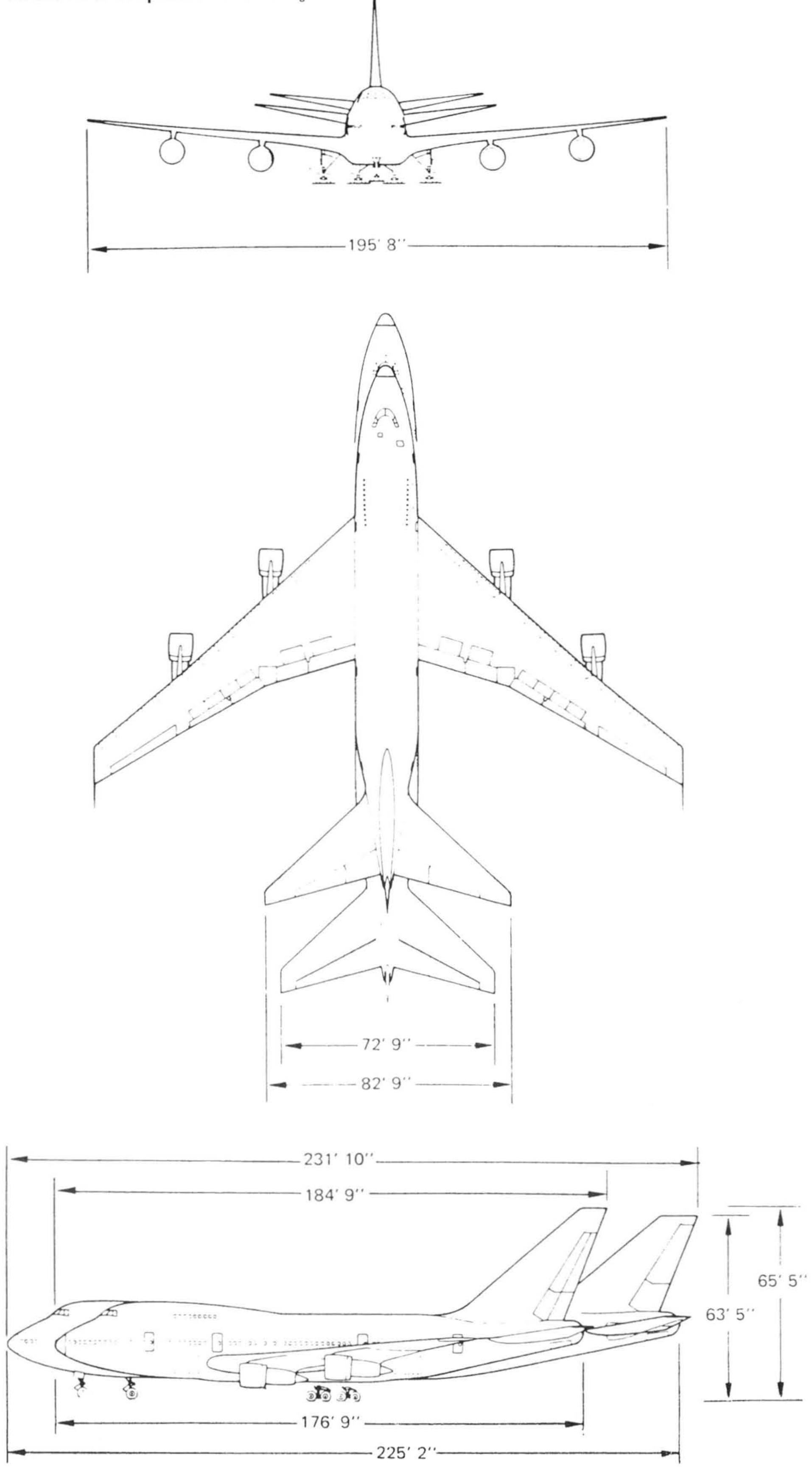


747SP aft body diagram.

Configuring the SP

In simple terms, Boeing shortened the 747 fuselage by 48ft 4in (14.7m) to 176ft 9in (54m). However, this process was not as straightforward as it may have appeared. The nose section remained unchanged, but two straight sections of fuselage and one tapered section had to be removed. A section of fuselage forward of the front-wing spar was removed, as was the roof section of the next section back. This latter was deleted in order to make room for the fairing of the raised upper deck, which now became flush with the fuselage over the mid-chord position of the wing rather than by the leading edge. Lastly, the large wing-fuselage fairing was replaced with a smaller, or 'cropped', fillet. (During flight-tests, this was found to create a local shock wave and was

747 and 747SP comparative sizes. Boeing



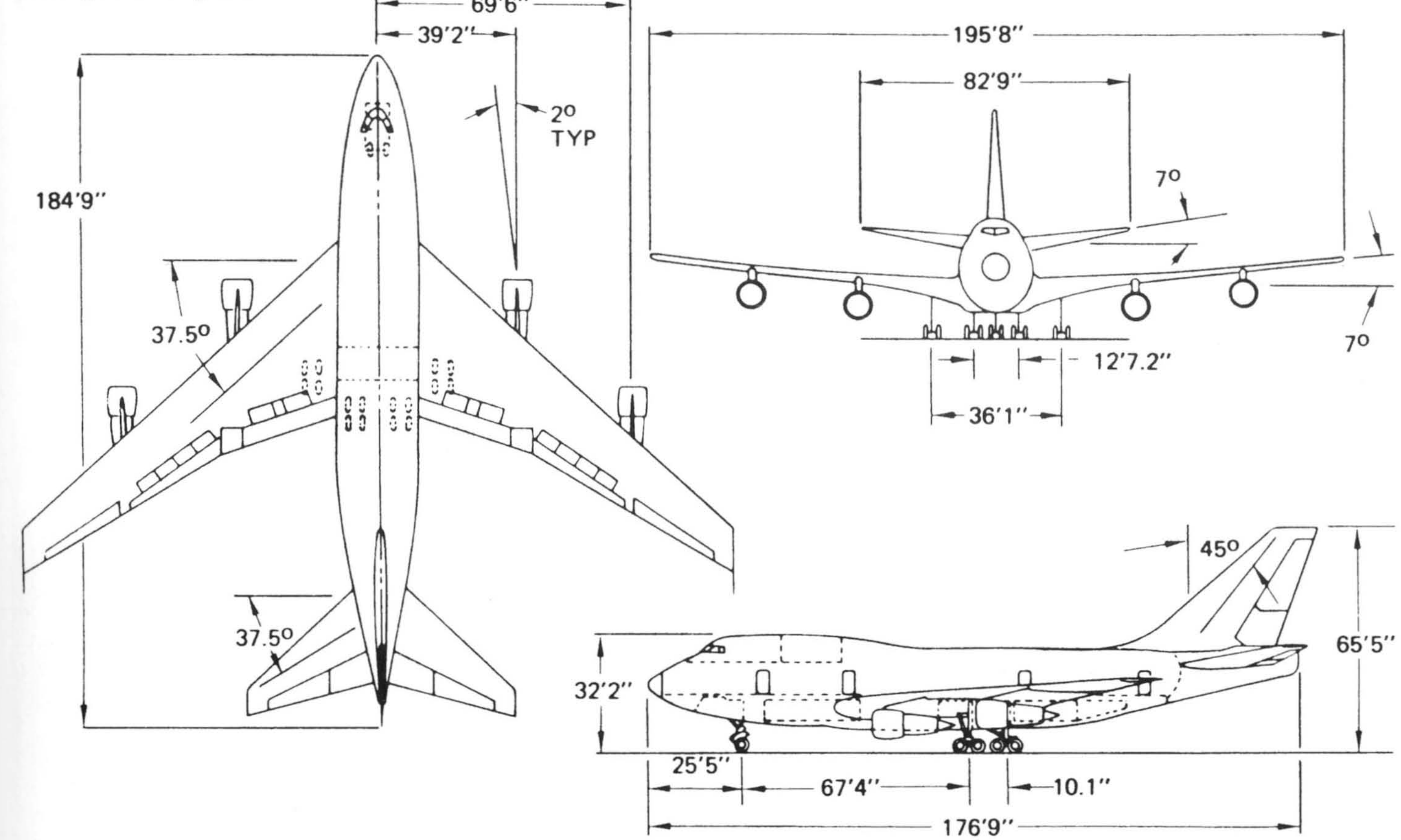
therefore redesigned with more contouring over the top of the wing.)

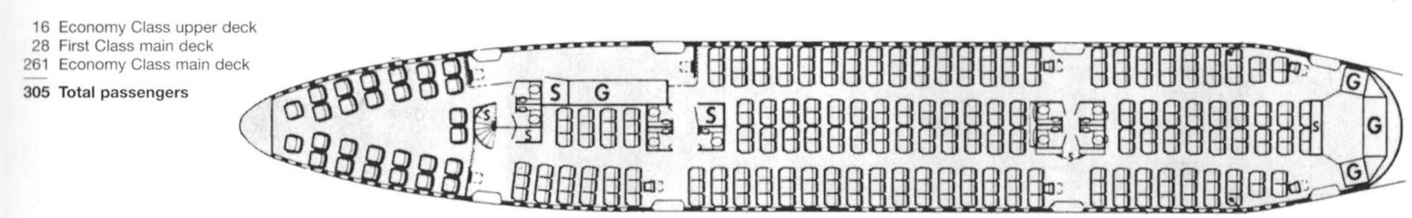
Additional stiffeners and sound-proofing were also added to the upper lobe section, mainly because of its proximity to the wing, and the front-wing spar/fuselage frame was also modified. Cabin doors were reduced to four per side. Major weight savings changes were made by using reduced-gauge materials for the spars, ribs, skin and stringers in the wing box and centre section, while the original triple-slotted trailing-edge flaps were replaced with single units. The span of the tail-plane was increased by 10ft (3m), and a taller fin was added, 24in (60cm) taller than the basic 747's tail, with double-hinged rudder. Seating was reduced to twenty-eight first-class passengers and 271 tourists on the main deck, plus thirty-two passengers on the upper deck.

The lighter-weight materials, and some innovative engineering, meant that the SP weighed in at about 42,000lb (19,050kg) lighter than the empty weight of the 747-100. Almost 12,500lb (5,670kg) of this was saved on the wing as a result of much simpler single-slotted flaps in place of the standard 747 triple-slotted arrangement. A shorter fuselage body accounted for a further 11,000lb (4,990kg) of weight loss. On the debit side, the improved tail unit added about 1,500lb (680kg), and the improved nose-wheel gear added a further 230lb (100kg); but overall, 44,100lb (20,000kg) was lost and the SP delivered an operating empty weight of 315,000lb (142,880kg). In comparison, the 747-100's operating empty weight was 360,000lb (163,300kg). Fuel capacity was increased to 50,359 US gallons (190,609 litres). Gross weight was reduced to 663,000lb (301,000kg). Several versions of two powerplants were available: General Electric CF6-45A2 or -50E2-F of 45,000lb (20,860kg) thrust, or Rolls-Royce RB.200-524B2, -52422 or 524D4 with 50,100lb (23,226kg) or 43,100lb (19,550kg) of thrust.

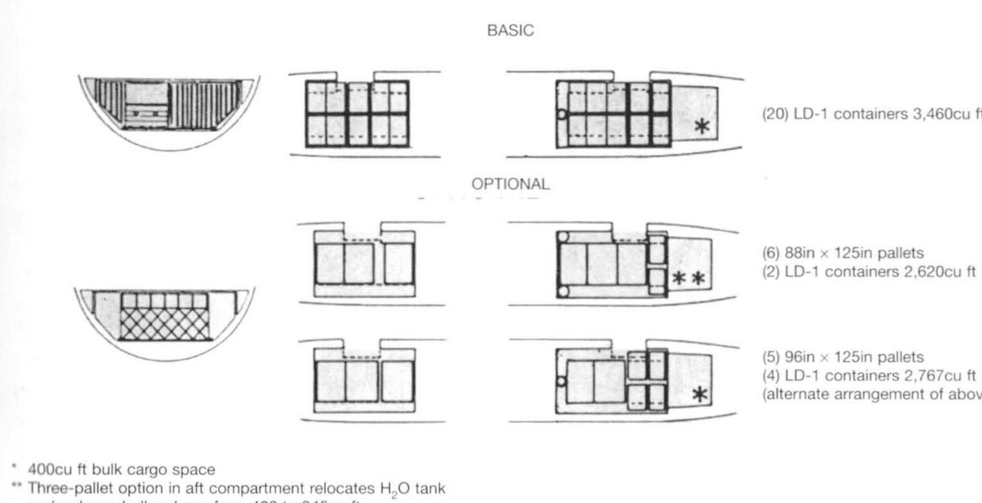
On 4 July 1975 Jack Waddell and his crew took the first 747SP (N747SP) aloft from Paine Field, and for three hours and four minutes they really 'wrung it out'. The crew carried out a preliminary evaluation of handling and systems, airspeed calibration and fuel consumption, they proved that the new flap system was trouble free, and then put the aircraft through the full speed range from stall right up to Mach 0.92. The SP-21 reached 30,000ft (9,000m) and 630mph (1,014km/h). Confidence was such that

747SP general arrangement.

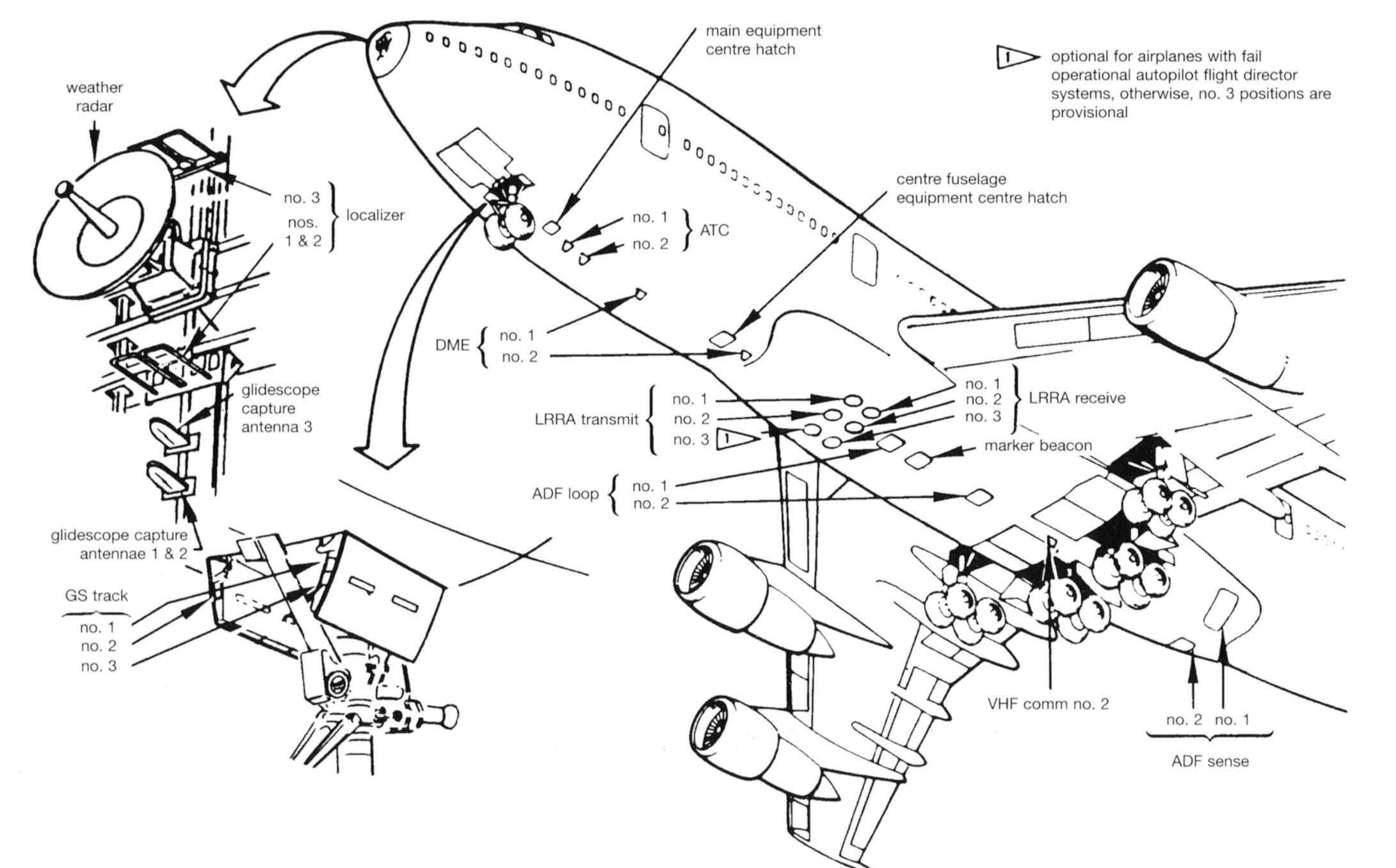




***(Above)* 747SP interior arrangement.**



The 747SP has ample space for passenger baggage and cargo in the 20 containers in the lower compartments. These compartments can also carry standard shipping pallets loaded 64in high. The bulk compartment will carry an additional 400cu ft of cargo.



747SP lower antennae locations.

SP-21 N530PA Clipper Mayflower **first flew on 4 July 1975 (N747SP), and was the first of ten SP-21s for Pan Am, when it was delivered on 26 April 1976. It is seen here taking off from a murky London-Heathrow on 19 October 1985. N530PA was acquired by United on 11 February 1986. The registration was cancelled in September 1995 and in February 1996 the aircraft was stored at Ardmore, Oklahoma. The aircraft had flown a total of 78,312 hours.** Graham Dinsdale

later that day it was taken up again on a second test flight lasting fifty-two minutes. By August 1975 the first two SPs (N247SP was the other) were flying, but problems encountered during the test programme with the cropped wing-fuselage fillet and stabilizer trim resulted in the certification target date of December 1975 having to be moved back to the following February. In the meantime, N747SP established a number of record-breaking long-distance endurance records.

Into Service

On 12 November 1975 N247SP flew nonstop from New York to Tokyo with 200 passengers in a flying time of 13 hours 33 minutes. On board was a fifteen-strong

party of representatives from JAL. The Japanese airline operated DC-8-62s on the same route, with a refuelling stop at Anchorage, Alaska. For a month after, other demonstration flights totalling 700,000 miles (1,126,300km) were made, including a 7,310-mile (11,760km) nonstop flight from Sydney, Australia, to Santiago, Chile, and a 7,140-mile (11,488km) flight from Mexico City to Belgrade. Certification of the 747SP by the FAA was made on 4 February 1976. On 5 March 1976 N533PA *Clipper Freedom* was accepted by Pan Am, and N532PA *Clipper Constitution* was delivered on 29 March, and the airline placed these two aircraft in service during April. On 1 May *Clipper Freedom* made a record-breaking around-the-world flight from John F. Kennedy Airport, New York, and return, via Delhi, India, and Tokyo, Japan in 46 hours 26 minutes. By the end of May three more SPs were accepted by Pan Am: N747SP (now N530PA) *Clipper Mayflower* on 26 April, N247PA (N531PA) *Clipper Liberty* on 17 May, and N534PA *Clipper Great Republic* on 28 May. (Two other SPs allocated to Pan Am, including N535PA *Clipper Mercury*, were later cancelled.) The five remaining SP Clippers were accepted during 1977–79, the last, *Clipper White Falcon*, being delivered on 11 May 1979.

In 1977 Pan Am had celebrated its fiftieth anniversary, but by the mid-1980s America's premier carrier was in deep financial trouble. Huge losses on its domestic routes by 1985 brought matters to a head, and on 22 April 1986 Pan Am agreed to sell its Pacific division to United Airlines for $750 million. The deal included the 747SP fleet and six Lockheed TriStars. (On 12 August 1991 a bankrupt Pan

SP-21 N538PA Clipper Fleetwing **taxiing at London-Heathrow. This aircraft first flew on 30 June 1978 and was delivered to Pan Am on 12 July 1978. In 1980 N538PA was renamed** Clipper Plymouth Rock. **It was withdrawn from service by United Airlines on 12 October 1994 and put into storage at Las Vegas, Nevada. It has been stored at Marana, Arizona, since 30 November 1995.** Ron Green

747SP Characteristics with JT9D-7 Engines

Engine	*JT9D-7A*	*JT9D-7AW**	*JT9D-7F**	*JT9D-7FW**
Maximum taxi gross weight (lb)	666,000	666,000	666,000	666,000
Maximum brake release gross weight (lb)	660,000	665,000	660,000	665,000
Design landing weight (lb)	450,000	450,000	450,000	450,000
Zero fuel weight (lb)	410,000	410,000	410,000	410,000
Operating empty weight (lb)	315,000	315,700	315,200	315,900
Structural payload (lb)	95,000	94,300	94,800	94,100
Cargo/baggage volume (cu ft)	3,860	3,860	3,860	3,860
Fuel capacity: gallons (US)	47,210	47,210	47,210	47,210
pounds (@6.7lb/gal)	316,300	316,300	316,300	316,300

* *options*

SP-21 N142UA, which first flew on 10 October 1975 (N347SP) and was delivered to Pan Am as N532PA *Clipper Constitution* **on 29 March 1976, pictured at Hong Kong on 10 September 1987. N532PA was acquired on 11 February 1986 by United Airlines, who finally withdrew this aircraft from service in July 1994.** Graham Dinsdale

SP-68 HZ-AIF first flew on 4 June 1981 and was delivered to Saudia Airlines on 23 June. Boeing

SP-68 HZ-AIJ of the Saudi Royal Flight taxiing at London-Heathrow. This aircraft, and SP-68 HZ-HM1B, is operated by No. 1 Squadron RSAF. Barry Reeve

B-1862, which was delivered to China Airlines on 6 April 1977, taking off from Schiphol on 14 April 1988. China Airlines bought B-1862 and three other SP-09s to provide a non-stop service between Taipei and San Francisco, and on the Anchorage–New York route. Previously, China Airlines' 747-200 series service to Los Angeles required a technical stop at Honolulu, Hawaii en route. With the introduction of MD-11 and 747-400 aircraft on its routes, B-1862 and two other China Airlines' SP-09s were transferred to its subsidiary company Mandarin Airlines. Graham Dinsdale

SP-31 N601AA of American Airlines taxiing at London-Heathrow on 18 January 1992. This aircraft first flew on 12 March 1980 and was delivered to TWA on 21 March. It is currently operated by Air Atlanta Iceland. Graham Dinsdale

SP-Z5 N60697 of the United Arab Emirates at London-Heathrow on 27 July 1989. This aircraft is now operated by the government of Abu Dhabi as A6-ZSN. Graham Dinsdale

SP-J6 B-2444 of the People's Republic of China airline CAAC (Civil Aviation Administration of China) at Frankfurt-Main on 23 February 1990. This was one of three SP-J6s received by CAAC from Boeing in 1980 (as SP-27, B-2454, was acquired late in 1982). B-2444 is now operated as B-2438 by Air China, which has superseded CAAC in airline operation. Graham Dinsdale

Executive jet – Arab style! SP-27 A40-SO, operated by the Royal Flight of Oman, in the BA maintenance yard at Heathrow on 31 August 1993 following servicing, shortly before entering the paint shop to have its all-over white livery with green and red cheatline applied. Note the Satcom 'hump' behind the flight deck. This 747SP, the 405th 747 built, was delivered to Braniff Airways in October 1979. As N603BN it was operated for five years by Braniff before being sold to the Omani government, who then spent three years having it converted to its present configuration. Oman acquired a second ex-Braniff SP-27 (N606BN – A40-SP), which was also operated by Pan Am and United. The third ex-Braniff SP-27 (N604BN) was acquired by Qatar Airways (A7-AHM). Graham Dinsdale

SP-94 YK-AHA November 16, **the first of two Special Performance 747s for Syrian Air, delivered on 21 May 1976 (the other is YK-AHB** Arab Solidarity, **which was delivered on 16 July 1976).** Barry Reeve

(Below) **SP-44 3B-NAG** Château du Reduit **under lease to Air Mauritius, at Paris-Orly, 31 May 1990. This aircraft first flew on 4 June 1976, and was delivered to South African Airways as ZS-SPC** Maluti **on 16 June 1976.** Graham Dinsdale

Am sold its remaining assets to Delta Airlines for $416 million in cash and the assumption of $389 million worth of liabilities. What was left of Pan Am's once mighty fleet was kept alive by Delta as a proving operation in Florida for flights to South America. On 4 December 1991, the day after Pan Am shed its Chapter Eleven protection, Pan Am was no more. Delta pulled the plug.)

The structural strength of the 747 was indisputably confirmed on 5 February 1985 when a China Airlines' SP-09, flying from Taipei to Los Angeles with 276 people on board, entered into a series of manoeuvres that no other 747 has had to endure. 747SP N4522V, piloted by Captain Min-Yuan Ho, had covered most of the flight across the Pacific during the night and early part of the dawn. At 10.16am the aircraft was about forty minutes from landing at LAX and cruising in broad daylight at 41,000ft (12,500m), when it encountered some light turbulence. Met reports had indicated that a stormy weather front extending from the Californian coast was moving out to sea, and below the 747 lay the black

(Top) **SP-09 B-1862 of Mandarin Airlines (formerly N8290V of China Airlines, its parent company) approaching Kai Tak Airport, Hong Kong, on 28 April 1998. Mandarin operates two of the four SPs originally delivered to China Airlines, B-1882 being owned by First Security Bank, and N4522V by Sanwa Business Credit.** Graham Dinsdale

(Bottom) **SP-38 VH-EAB** City of Winton, **the second of two SP-38s for Qantas, taking off from Sydney on 15 October 1988.** Graham Dinsdale

clouds of this storm front which reached from 11,000ft (3,350m) at their base to the tops of high cloud at 37,000ft (11,280m). Ho called for reduced engine power, but the number two appeared to be running badly, and after a quick consultation, the crew decided to shut it down. (It later transpired that there was nothing wrong with the engine.) The autopilot meanwhile tried to counteract the loss of the inner right-hand engine, and for a time the system kept the wings level. (The autopilot can handle a rolling error of up to 22 degrees from wings level.)

Captain Ho asked for permission to descend to 30,000ft (9,000m), the maximum height at which engines can be restarted. This was given, and he disengaged the autopilot before commencing his descent. Ho was under the impression that the wings were level when he disengaged the autopilot, but in fact they were not. (What had happened was that the autopilot had over-compensated for first the turbulence, and then the engine being shut down, and it had not been able to prevent the 747 entering a tightening 'aileron roll' to starboard as they dropped through cloud.) Ho had the control of the aircraft wrenched from his grasp. N4522V performed an extraordinary series of convulsions, rolling until the wings were vertical, then nose-dived close to the speed of

SP-21 N149UA of Tajik Air: it was originally ordered by Pan Am (where as N540PA it was named Clipper White Falcon, **later** Clipper Star of the Union**), and was then acquired by United Airlines with the demise of Pan Am, and later, by Amadeo Corporation/Government of Brunei (V8-AC1) arriving at Hamburg on 23 December 1998. V8-AC1 was sold to the Bahrain Amiri Flight with the intention of becoming A9C-1SA. After the death of the Sheik of Bahrain (whose first name was Isa), the aircraft became A9C-HHH.** Barry Reeve

747SP Production Totals

Reg.	*Model*	*Customer*	*No. Built*
EP-IAA	SP-86	Iranair *Fars*	2
EP-IAB	SP-86	Iranair *Kurdistan*	
N530PA	SP-21	Pan Am *Clipper Mayflower*	5
N531PA	SP-21	Pan Am *Clipper Liberty*	
N532PA	SP-21	Pan Am *Clipper Constitution*	
N533PA	SP-21	Pan Am *Clipper Freedom*	
N534PA	SP-21	Pan Am *Clipper Great Republic*	
21027	SP-21	(Pan Am)	not built
21028	SP-21	(Pan Am)	not built
EP-IAC	SP-86	*Khuzestan*	1
ZS-SPA	SP-44	SAA *Matroosberg*	3
ZS-SPB	SP-44	SAA *Outeniqua*	
ZS-SPC	SP-44	SAA *Maluti*	
YK-AHA	SP-94	Syrian Arab *November 18*	2
YK-AHB	SP-34	Syrian Arab *Arab Solidarity*	
ZS-SPD	SP-44	SAA *Majuba*	3
ZS-SPE	SP-44	SAA *Hantam*	
ZS-SPF	SP-44	SAA *Soutpansberg*	
B-1862	SP-09	China Airlines	1
N536PA	SP-21	Pan Am *Clipper Lindbergh*	5
N537PA	SP-21	Pan Am *Clipper High Flyer*	
N538PA	SP-21	Pan Am *Clipper Fleetwing*	
N539PA	SP-21	Pan Am *Clipper Black Hawk*	
N540PA	SP-21	Pan Am *Clipper White Falcon*	
HZ-HM1B	SP-68	Saudi Arabian	1
EP-IAD	SP-68	Iranair	1
21785/86	SP-27	Braniff	2
21932/34	SP-J6	CAAC Beijing	3
21961/63	SP-31	TWA	3
21992	SP-27	Braniff	1
22298	SP-09	China Airlines	1
22302	SP-27	CAAC Beijing	1
22483/84	SP-85	Korean Air	2
22495	SP-38	Qantas	1
22503	SP-68	Saudi Arabian Airlines	1
22547	SP-09	China Airlines	1
22672	SP-38	Qantas	1
22805	SP-09	China Airlines	1
YI-ALM	SP-70	Iraqi *Al Qadissiya*	1
A6-ZSN	SP-P6	Abu Dhabi	1
			Total: 44

sound – it fell at a rate of 18,000ft (5,500m), or over 3 miles (5km) a minute – the centripetal forces pinning both passengers and crew to their seats; finally it turned upside down. (The stresses were later calculated to be ten to twelve times the force of gravity.) The wild gyrations of the spiralling aircraft, combined with the absence of visual references, not unnaturally completely disorientated Ho – he was clearly the victim of vertigo, or spatial disorientation. A scan of all the instruments would have revealed the 747's true flight attitude, but the three remaining engines had all flamed out and Ho's mind concentrated solely on the power dive, to the exclusion of all else.

Parts of the undercarriage and pieces of the control surfaces were ripped off, and the APU in the tail was torn from its mountings. It was only when the 747 broke out of cloud at 11,000ft (3,350m) and Ho could identify the horizon that the crew could attempt to level out. If the storm front had extended to near the surface of the sea they would not have overcome their disorientation and the aircraft would have plummeted into the Pacific. It had lost parts of its tail and its wings had buckled in the gyrations, but in spite of this apparently crippling damage, the 747SP responded, and in clear air at 9,000ft (2,750m) the crew managed to relight the three engines and stabilize the aircraft.

N4522V was diverted to San Francisco where Ho made a successful emergency landing. Incredibly, only two of the 276 passengers and crew suffered serious injury. It is thought that had the pilots, who had been flying for ten hours when the engine was shut down, disconnected the autopilot and taken full manual control in time, they might have prevented the frightening series of events. The incident led to renewed pilot training and an improvement in both the computer-based auto systems.

CHAPTER SEVEN

Freighters

Although the 747-100 was designed to carry freight from the very outset and was offered in all-cargo and passenger-cargo convertible configurations, no Model 747-100s were ever built as such. Orders were received for both versions, but these were subsequently cancelled or converted to all-passenger aircraft before delivery. Originally, Boeing had confidently expected that up to half of the first 400 747s bought by airlines would be cargo-carrying aircraft. This projection was based mostly in the belief that the introduction of SST aircraft would see passenger yield moving to the new generation supersonic aircraft, leaving the early 747s to be converted to cargo-carrying aircraft.

Model 747-100SF

The supersonic revolution never really materialized, however, and for the first three years of the 747's life, Boeing received only one firm order for a cargo-carrying aircraft, and this was a new-build -200F, for Lufthansa. Also, the early engines used to power the 747-100s, which grew ever heavier as modifications and increased fuel loads were added to their gross weight, were just not powerful enough to deliver the thrust and take-off speed margins required by freight-carrying 747s fitted with nose and/or side doors.

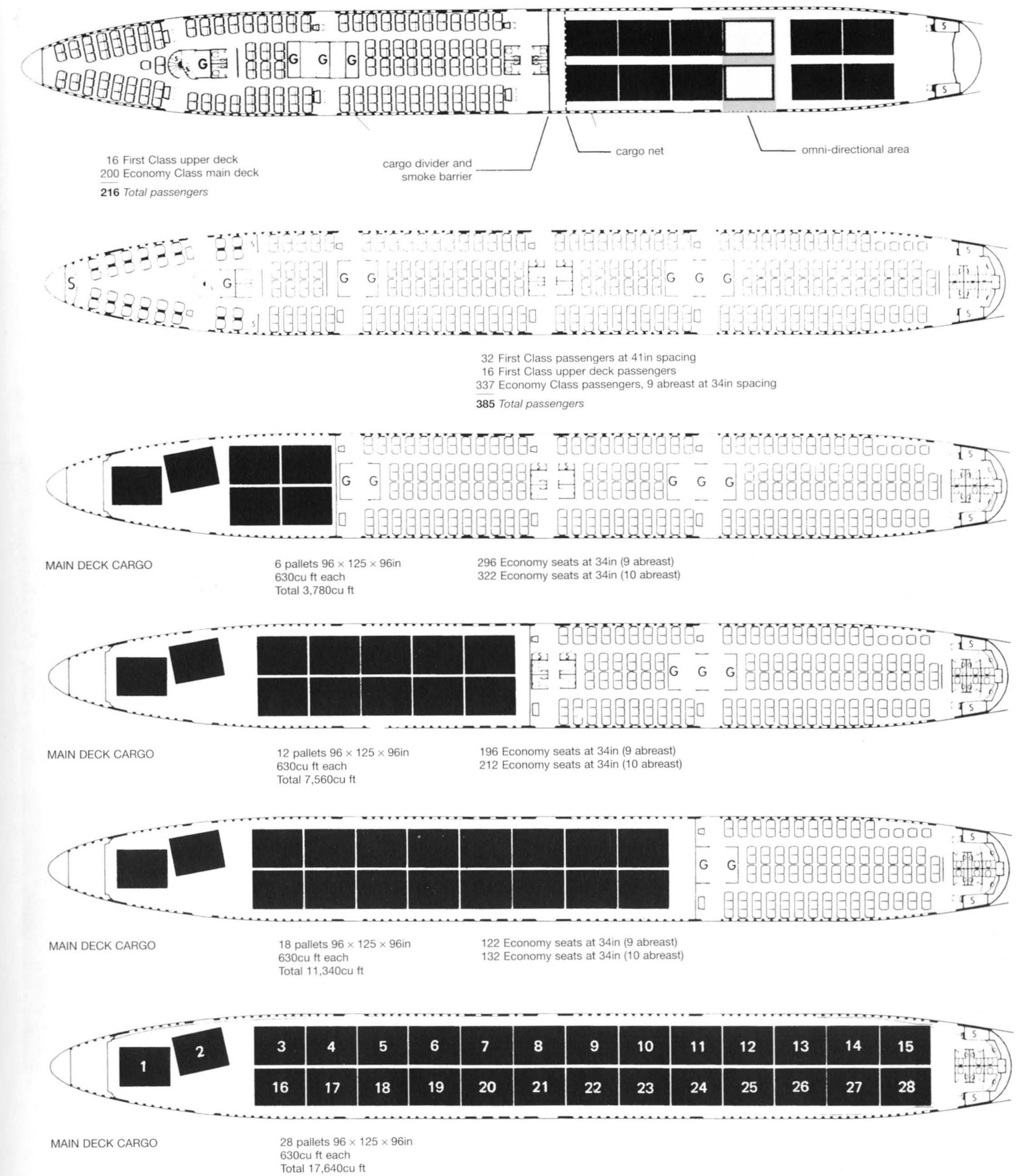
View looking forward of the rear cabin of a 747-100C, which has its ceiling removed. Conversion of 747-100s from passenger-carrying to cargo-carrying aircraft was carried out at the Boeing-Wichita Modification Responsibility Center in Kansas. Starting in 1974, the cabins on ex-United Airlines'-100s for cargo carrier Flying Tigers were gutted and rebuilt with a strengthened main cargo-deck floor, a cargo-handling system was installed, and a 120 × 134in (305 × 340cm) side cargo door was created in the left side between the trailing edge of the wing and the tail. Boeing

This view, looking aft, shows containers being loaded via the side cargo-door in what appears to be a gigantic underground tunnel. The added door allows main-deck combination, or 'Combi', loading: either all passengers, all cargo, or passengers and up to twelve pallets or containers. Containers up to 8ft (2.4m) high can be carried forward of the cargo door, and containers 10ft (3m) high can be carried aft of the door if the normal passenger ceiling is removed, as in this photo. Boeing

This situation only began to change in 1973–74 when the oil crisis caused world economic recession which saw a rapid downturn in passenger loads, especially on the transatlantic routes. As a result, fleets generally were forced to cancel or unload some of their existing large aircraft such as the 747-100s onto the second-hand market. After conversion, many were put into service as cargo-carrying aircraft.

The conversion of 747-100s from passenger-carrying to cargo-carrying aircraft was carried out at the Boeing-Wichita Modification Responsibility Center in Kansas. Starting in 1974, the cabins on ex-United Airlines' -100s for cargo carrier Flying Tigers were gutted and rebuilt with a strengthened main cargo-deck floor, a cargo-handling system was installed, and a 120 × 134in (305 × 340cm) side cargo door was created in the left side between the trailing edge of the wing and the tail. These modifications increased the maximum take-off weight to 755,000lb (342,470kg). Eventually, twenty-four aircraft were converted to 747-100SF configuration, with the others being prepared for Pan Am and the Imperial Iranian Air Force. In addition, early in 1974 two 747-129s were converted by Boeing-Wichita for SABENA with the addition of a strengthened aft deck to carry up to six freight pallets, and a side cargo door 11ft 2in (3.4m) wide and 10ft 3in (3.1m) high on the left side of the fuselage behind the wing. To keep rain from running in from the top of the fuselage when the door was open, a rain deflector strip was installed above the door, projecting several feet to each side.

The added door allows main-deck combination – or 'Combi' – loading: either all passengers, all cargo, or passengers and up to twelve pallets or containers. Containers up to 8ft high (2.4m) can be carried forward of the cargo door and containers 10ft (3m) high can be carried aft of the door if the normal passenger ceiling is removed. Cargo and passenger areas are separated by a removable bulkhead, the passengers being seated forward of the cargo. By early 1977, more than forty 747s had been delivered with, or modified to have, the side cargo door.



Cargo options.

Model 747-200F

The 747-100s were not powerful enough to carry an upward-hinged nose door and to operate efficiently as pure freighter aircraft; however, when the higher thrust P&W JT9D engine became available Boeing *could* at last press ahead with a pure freighter version of the 747, and in 1970 committed $54.2 million into developing the -200A to this end – it was the first 747 to feature straight-in loading of bulk cargo through a hinged-up nose-hatch which Boeing termed a 'visor'. The width of the cabin permits two 8ft wide by 8ft high (2.4 × 2.4m) containers – the longest of which is 40ft (12m) and a 747-200F can carry six – to be loaded side by side through the nose. A further $15 million was spent developing an optional 11 × 10ft (3.3 × 3m) side door which allows containers 10ft (3m) high to be loaded on board and carried in the rear part of the cabin. At first there seemed little chance of a sizeable return on these huge investments, because for the first two years only one of these big aircraft was put into service. Sales eventually picked up, however, and the company's faith in the pure freighter design was rewarded, some seventy-three -200Fs being built over twenty-one years before production switched to the 747-400F in 1991.

Distribution of the cargo as it is loaded is by means of a powered transfer system built into the cabin floor. With a central station at the nose door, two people can distribute and stow upwards of 250,000lb (113,400kg) of main-deck cargo in half an hour. An automatic weight-and-balance computer makes it unnecessary to calculate manually the weight and movement of each container. If the load is distributed beyond limits, the distribution system shuts down. Cargo loading is normally by means of mobile ground equipment, but to serve airports without such facilities Boeing developed an on-board cargo loader that is carried in the nose of the aeroplane. This can lift units of up to 30,000lb (13,600kg) through either the nose or the side door. The 29ft- (8.8m-) long unit, which weighs 14,000lb (6,350kg) is carried in the forward end of the cabin. It does not entirely displace cargo in that space because it can contain two 8 × 8 × 9ft (2.4 × 2.4 × 2.7m) containers.

In addition, the fuselage was revised to delete all passenger doors except one and five on the left side of the aircraft. All passenger windows are also deleted except the windows in doors one and five. Three small windows were added on the left side and two on the right side for viewing the wing- and cargo-loading operations. The aircraft systems, such as the air-conditioning system were revised to suit freighter use.

D-ABYE, the first -200F (its temporary US registration during certification testing was N1794B) was rolled out on 14 October 1971, and first flew on 30 November. Following certification on 7 March 1972, with the designation 747F as a pure freighter, D-ABYE *Cargonaut* was accepted by Lufthansa two days later, entering service on the Frankfurt–New York route on 19 April. *Cargonaut* could carry a maximum payload of 260,000lb (118,000kg) – three times that of the 707 – nearly 3,000 miles (4,830km). This aircraft is still in service, with Korean Air, and was the first 747 to exceed 100,000 flying hours.

Late in 1974, JAL, Seaboard World and Air France took delivery of -200Fs (in Air France service they became known as 'Pelicans', a reference to the upward-opening nose door). The first 747-200F to have the side cargo door fitted was -245F N701SW, the 242nd 747 built, which was delivered to Seaboard World Airlines on 31 July 1974. The later availability of the Pratt & Whitney JT9D-70A engine permitted an increase in aircraft take-off weight from the original 785,000lb (356,080kg) to 820,000lb (371,950kg), so the -245F was returned to Everett for conversion. The seventy-third and final -200F built was a -281F received by Nippon Cargo Airlines on 19 November 1991.

747-100s were not powerful enough to carry an upward-hinged nose door and operate efficiently as a pure freighter aircraft; however the higher-thrust P&W JT9D engine enabled Boeing to at last press ahead with a pure freighter version of the 747, and in 1970 they committed $54.2 million to developing the -200A to this end. It was the first 747 to feature straight-in loading of bulk cargo through a hinged-up nose-hatch, which Boeing termed a 'visor'. The width of the cabin permits two 8ft wide by 8ft high (2.4 × 2.4m) containers (the longest of which is 40ft (12m) and a 747-200F can carry six) to be loaded side by side through the nose. A further $15 million was spent developing an optional 11 × 10ft (3.3 × 3m) cargo side door which allows containers 10ft (3m) high to be loaded on board and carried in the rear part of the cabin. Boeing

747-200F Characteristics with JT9D-7AW engines

Maximum taxi gross weight (lb)	778,000	788,000*
Maximum brake release gross weight (lb)	775,000	785,000
Design landing weight (lb)	630,000	630,000
Zero fuel weight (lb)	590,000	590,000
Operating empty weight (lb)	337,000•	337,000•
Structural payload (lb)	253,000	253,000
Cargo/baggage volume (cu ft)	23,630	23,630
Fuel capacity: gallons (US)	51,430	51,430
pounds (@6.7lb/gal)	344,580	344,580

∗ option; • includes 16,644lb tare weight

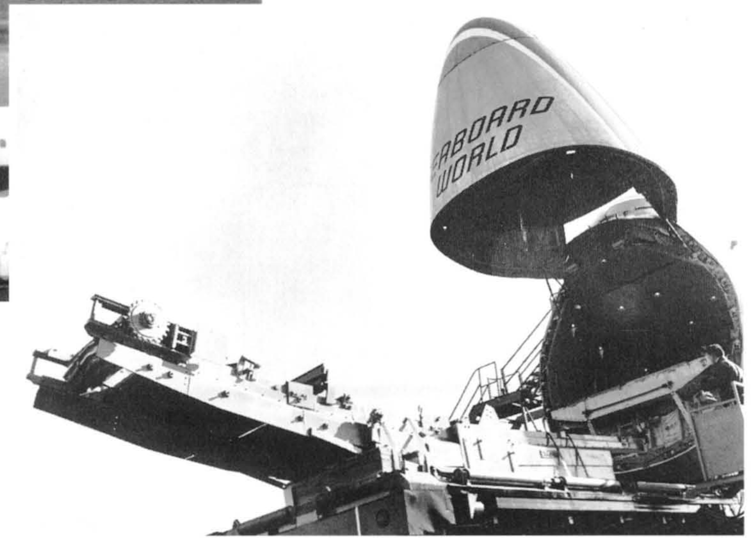
Cargo Volume/Weights Summary

Cargo module	Size (inches) W × L × H	Max. volume (cu ft)†	Tare weight (lb)	Max. weight (lb)	Quantity per airplane	Total volume (cu ft)	Total tare (lb)
Main deck pallets	96 × 117.75 × 96	585	350	12,500	30¶	17,550	10,500
	96 × 125 × 96	630	284	15,000	28**	17,640	7,950
	88 × 125 × 96	580	260	15,000	28**	16,240	7,280
	88 × 125 × 88*	447	260	13,300	28**	12,516	7,280
	88 × 108 × 96	498	225	12,960	32¥	15,936	7,200
	88 × 108 × 96•	490	340	10,000	36¥	17,640	12,240
Main deck containers	96 × 117.75 × 96	550	825	12,500	30¥	16,500	24,750
	96 × 238.50 × 96	1,160	1,650¥	25,000	13¥	15,080	21,450
	96 × 359.25 × 96	1,775	2,475¥	35,000	7¥	12,425	17,325
	96 × 480 × 96	2,350	3,300¥	45,000	5¥	11,750	16,500
Lower deck pallets	96 × 125 × 64	415	284	11,100	9¥	3,735	2,560
	88 × 125 × 64	379	260	10,200	9¥	3,411	2,340
	88 × 108 × 64	327	225	10,200	9¥	2,943	2,025
	88 × 108 × 64•	320	340	10,200	9¥	2,880	3,060
Lower deck containers	186 × 60.4 × 64	350	470	7,000	15	5,250	7,050
	92 × 60.4 × 64	173	270	3,500	30	5,190	8,100
	79 × 60.4 × 64	158	200	3,500	30	4,740	6,000
Bulk cargo compartment	–	800	–	14,880	–	800	–

∗ 707 Contour; • MIL 463L; † Internal volume, ¥ Estimated; ¶ Option; ∗∗ 29th pallet optional

FREIGHTERS

(Left) **In 1974 JAL, Seaboard World, and Air France took delivery of -200Fs. The first 747F to have the side cargo door fitted was 747-245F (N701SW), which was delivered to Seaboard World Airlines on 31 July 1974 (this aircraft is still in service, with Atlas Air). In all, Seaboard took delivery of four -245Fs, and N704SW is pictured at London-Heathrow on 10 June 1978.** Graham Dinsdale



(Right) **A 29ft 6in- (9m-) long conveyor frame of a Conway Mucker weighing 9,700lb (4,400kg) being lifted to the main deck of a Seaboard 747 containership. All four -245F containerships were subsequently acquired by Flying Tigers.** Seaboard World Airlines

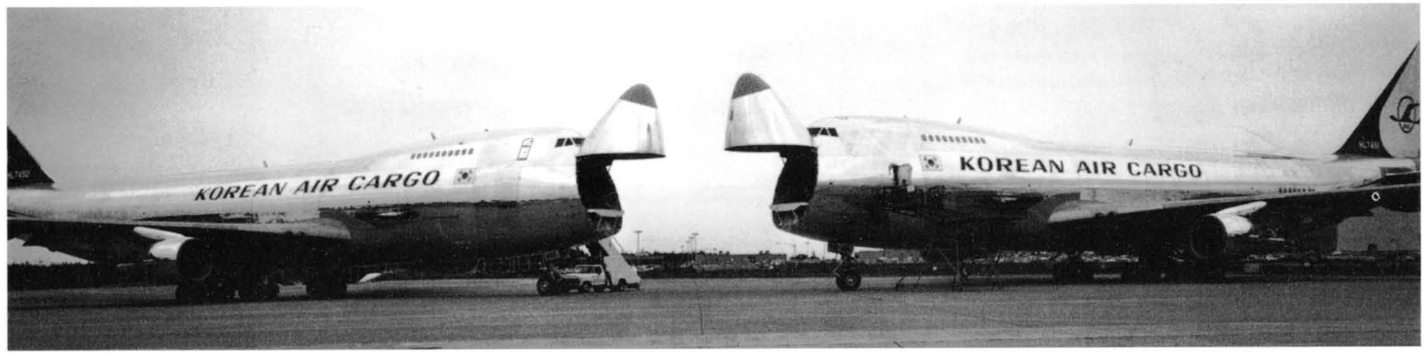
(Below) **A 68,500lb (31,070kg) piece on the ramp in the foreground prior to loading aboard a Seaboard World Airlines' 747 containership on the specially constructed loading platform (right).** Seaboard World Airlines

A 747 freighter of Flying Tigers, the Airfreight Airline, being loaded. This famous air freight company was taken over by Federal Express in 1989. GMS

747-228F F-BPVR (N1783B), one of seven -228Fs purchased by Air France, delivered on 13 October 1976. In Air France service 747 freighters are known as 'Pelicans', a reference to the upward-opening nose door. The sixty-seventh and final 200F built (F-GCBK) was received by Air France in October 1991. Boeing

The 747 used as a freighter brought about a major revolution in the large-scale airlift of cattle. Previously, the animals had been walked singly up a ramp and into the aeroplane cabin, where they were tethered. Obsolescent aeroplanes, or others near the ends of their service lives, were usually used for this work because of the severe airframe corrosion resulting from animal wastes. The 747, with its large cabin and side-door loading, changed because the animals could be containerized: now, up to six cows can be loaded into one leak-proof, open-top container and lifted aboard; up to 118 cows can be carried in a single 747.

The speed and range of the 747, even for trans-Pacific flights from the United States to the Orient via Alaska, make it unnecessary to unload the animals at intermediate stops, and thanks to the containers, the aeroplane is relatively clean at journey's end. The major change to a 747 used regularly for cattle lift is an increase



(Top) **747-2B5BFs HL7452 and HL7451, the first two of five 747 freighters for Korean Air Cargo, which took delivery of both aircraft on 25 June 1980.** Boeing

(Above) **747-2B5BF HL7451 of Korean Air Cargo in flight.** Boeing

747-2B5BF HL7452 of Korean Air Cargo being loaded. GMS

in the capacity of the cabin air-conditioning system.

Stretched Freighter Proposals

At the start of the 1970s Boeing looked at several ways of creating a high-capacity passenger and freight aircraft to revitalize the sagging 747 freight market. Though ways could be found to increase the payload of the 747, each method employed incurred a penalty in that the 747's range would be reduced as a result. And once again, Boeing were restricted by the limitations imposed by the engine technology then currently available. To increase the payload by 75,000lb (34,020kg) to 275,000lb (124,740kg), for instance, would involve stretching the 747 fuselage, and at the same time place reliance on Pratt & Whitney to develop the JT9D engine further to deliver 53,000lb (24,040kg) of thrust. (The P&W JT9D-7F/7FW engine, which produced 48,000lb (21,770kg) dry/50,000lb (22,680kg) wet thrust, finally became available in 1975, followed by the 54,000lb- (24,490kg-) thrust JT9D-7R4G2.) However, this would effectively reduce the 747's range to 3,450 statute miles (5,550km) which would prevent the new aircraft flying the lucrative transatlantic freight routes between the USA and Europe.

To overcome the range limitations, Boeing proposed wing-root extensions, or using an extended wing and mating it to a double-deck body. However, this would have raised the super freighter's gross weight to more than 1,000,000lb (453,600kg) and a payload of 300,000lb (136,080kg), and this combined weight increase would have required much more powerful engines than were at first envisaged. Studies into higher-capacity passenger-freight aircraft were finally consigned to the waste-paper basket when it was realized that to power the new super freighter, the engines would each have to produce between 65,000–75,000lb (29,500–34,000kg) of thrust, something that was clearly impossible at this time.

Engine-mounting Problems

Early in the 1990s an alarming engine-mounting problem was diagnosed on some 747s, the first being -2R7F LX-ECV, the 482nd 747 to be built, and which first flew on 30 September 1980. It was delivered to Cargolux on 10 October, who used it until the aircraft was bought by China Airlines on 26 February 1985, when it was re-registered B-198. After almost seven years' operation by Air China, on 29 December 1991, B-198 crashed into the Taiwanese mountains. Crash investigators discovered that the right wing inboard engine was missing: using state-of-the-art underwater diving equipment, it was eventually found in July 1992 on the seabed in the Formosa Straits; when it was raised to the surface, the strut assembly was found to be missing (it was finally discovered in April 1993).

The loss of a second -200F on 4 October 1992 heightened fears that there were structural problems with the 747's engine mountings. This time -258F 4X-AXG, belonging to El Al, lost both its starboard engines shortly after take-off from Amsterdam, Holland. (The aircraft had first flown on 7 March 1979 and had been delivered to the Israeli airline twelve days later.) It crashed at Bijlmermeer while the pilot was trying to return to the airport, and all four crew and more than sixty people travelling on the aircraft died.

A third incident involving 747 engine mountings occurred in March 1993 when an Evergreen International Airlines' 747-100F lost an engine just after take-off from Anchorage International Airport in Alaska. The engine fell into a car park of a shopping mall, though fortunately no one was injured, and the aircraft was able to land safely. The subsequent inquiry placed the blame for the accident on severe turbulence causing the entire engine pylon to fail.

By this time the engine mountings on all 900-plus 747s in service were being closely inspected. The engines were connected to the wing in four places: an upper mount was attached to the front spar, a rear diagonal brace to an under-wing fitting, and two mid-spar mounts beneath the wing. Inspection revealed that the engine-mounting 'fuse' (or break-point) pins were particularly corroded, especially in the structure of the early 747 models, though even the pins on the newer aircraft were clearly showing signs of corrosion. Originally Boeing had designed the engine mountings so that in the event of serious problems in flight, or impact in a crash on the ground, the engines would break off and fall away to prevent any further structural damage to the wing or rupture of the fuel tanks.

747-2J6BC B-2446 of Air China Cargo. This aircraft was first delivered to CAAC on 20 December 1983, transferring to Air China on 1 July 1988. Boeing

747-273C N7449WA on lease to Korean Airlines in January 1977. This aircraft was delivered to World Airways on 10 June 1974 and is currently operated by Evergreen International Airlines as N470EV. GMS

A major redesign of the engine mountings was instigated and in June 1993 Boeing publicly stated that the modification involved inserting two 9.5in (24cm) stainless-steel mountings manufactured from corrosion-resistant steel instead of carbon steel, in between the mid-spar fitting. The two new mountings were designed to take over from the four existing connections, so that if these were to fail, the two new mountings would stop the engine falling off in flight. At the same time, new mid-spar fittings of a larger size were installed, while a stronger diagonal brace and upper link was used on new-production -400s. At a cost of about $1 million per aircraft, each 747 had to have all four pylons removed, the wing root and ribs inspected and repaired, and the modified pylons reattached. The total cost of the repairs and inspection was shared jointly between Boeing and the airlines, whose aircraft were effectively out of action for between thirty-five and forty-two days. Some of the major 747 carriers opened up their own modification centres and carried out the repairs and inspections themselves and on behalf of other airlines.

Model 747-200C Passenger/Freighter

While passengers can conceivably be carried on the upper deck of the 747-200F, this is rarely done and Boeing realized that if it could offer carriers a more versatile 747-200C, one which could be configured for either an all-passenger, an all-freight, or a combination load, there was the distinct possibility that additional 747 sales would result. Such an aircraft could be used for just passengers in the summer when cargo traffic was low, and for freight-carrying during winter months when the situation was normally reversed. Boeing therefore committed $14.6 million into developing the 747-200C to operate in five different cargo- and passenger-loading arrangements. Also fitted with a hinged nose, it has a cargo distribution system built into the main deck floor, and the passenger flooring is installed above the cargo rollers. Conversion from all-passenger to all-cargo requires that the aircraft be out of service only twenty-four hours or less. Partial changes can be made more quickly, frequently within the time that is required for normal routine

Specification – 747-200C

Powerplant:	Four 43,500–53,000lb (19,700–24,000kg) Pratt & Whitney JT9D, 52,500lb (23,800kg) General Electric CF6-50E or 50,100lb (22,700kg) Rolls-Royce RB211-524B; fuel capacity 47,210–53,160 US gal (178,690–201,210ltr).
Weights:	Gross 775,000–833,000lb (352,000–378,000kg).
Dimensions:	Length 231ft 10in (70.65m); height 63ft 5in (19.50m); wingspan 195ft 8in (59.6m); wing area 5,500sq ft (511sq m).
Performance:	Cruising speed 600mph+ (965km/h) Ceiling 40,000ft (12,000m) Range 6,000 miles (9,700km).
Capacity:	235,000lb (107,000kg) cargo.

747-283B LN-RNA Magnus Viking **of SAS at Los Angeles International Airport in November 1980. This aircraft was delivered to SAS on 27 October 1977, converted to a -238M Combi and leased to Avianca (Aerovias Nacionales de Columbia) on 3 August 1982 (HK-2910X). On 27 November 1983 it crashed late at night on approach to Madrid's Barajas Airport with 182 people on board at the end of the flight from Paris. There was only one survivor.** via Barry Reeve

747-2J9F EP-ICA of Iran Air at Frankfurt on 27 August 1987. This aircraft was one of four ex-IIAF -2J9Fs (5-8114) bought new from Boeing in the late seventies, which in 1979 when the Shah of Iran was deposed was transferred to Iran Air. Graham Dinsdale

(Above) 747-2B5BF HL7451 of Saudia on finals at Schiphol, 14 April 1988. Graham Dinsdale

(Left) 747-2R7F LX-DCV, one of two freighters bought new from Boeing by Cargolux, the other being LX-ECV, which was subsequently bought by China Airlines (B-198) in 1985. B-198 was written off in a crash on 29 December 1991 at Wanli village, Taiwan, after an engine detached in flight. LX-DCV is now operated by Atlas Air. Boeing

(Below) 747-230F D-ABZI Australia, which was delivered to Lufthansa Cargo Airlines on 29 June 1988. Barry Reeve

747-246F JA8180 first flew on 29 July 1987 and was delivered to JAL Cargo on 11 August 1987. It is pictured at San Francisco in 1996. Graham Dinsdale

747-2D7B/SCD N522MC (HS-TGB) of Atlas Air/Thai Cargo at Frankfurt on 25 May 1997. Graham Dinsdale

maintenance. Gross weight is 833,000lb (377,850kg) with either Pratt & Whitney JR9D-7R4G2 or General Electric CF6-50E2 engines.

The first aircraft, 747-273C N747WA, the 209th 747 built, was rolled out at Everett on 28 February 1973, and was flown for the first time on 23 March. After certification on 24 April it was delivered to World Airways on 27 April. The aircraft was later leased to several carriers, including Pan Am, where it was named *Clipper Mercury*; it was finally retired by owners Evergreen in November 1988.

Unfortunately the convertible never fully realized its sales potential, with only thirteen being sold between 1973 and 1988.

Model 747-200M Combi

Although sales of the 747-200 freighter and -200C passenger/freighter were disappointing, airlines such as Air Canada, KLM and SABENA have taken to Boeing's -200M Combi version, largely because it offers six main-deck cargo positions, which permit the same passenger capacity as a wide-body DC-10 or TriStar, and the cargo capacity of a DC-8 or 707 freighter. No Model 747-200Ms have been built as such from new: the designation in fact applies to 747-200Bs, usually without the nose-loading feature, that have been modified to incorporate a side-loading cargo door in the fuselage, aft of the wing.

The first production 747-200B Combi – -233M C-GAGA for Air Canada, the 250th 747 built – was rolled out at Seattle on 30 October 1974, and it flew for the first time on 18 November. The aircraft could carry 365 passengers in its all-passenger configuration, or it could take a maximum main-deck cargo load of 176 passengers and twelve cargo pallets; it was delivered on 7 March 1975, and put into service on the London–Toronto route where it replaced a stretched DC-8. By the end of 1987, sixty-five 747-200Bs had been converted to 747-200Ms. Altogether seventy-eight series 200 Combis were delivered between 1975 and 1988. Three aircraft were lost between 1983 and 1987: 747-2283M HK-2910X, on

747-123F/SCD N672UP of United Parcel Service (UPS) on approach to Kai Tak on 28 April 1998. This aircraft is the 119th 747 built: it flew for the first time on 17 March 1971, and was delivered to American Airlines on 16 April 1971. Graham Dinsdale

***(Opposite page, top)* 747-132/SCD N803FT of Flying Tigers. This aircraft was originally delivered to Delta Air Lines on 22 October 1970; it was converted by Boeing to a Combi with a side cargo door aft of the wing, and sold to Flying Tigers on 1 July 1977. The aircraft is still in service, with Polar Air Cargo (N856FT).** Boeing

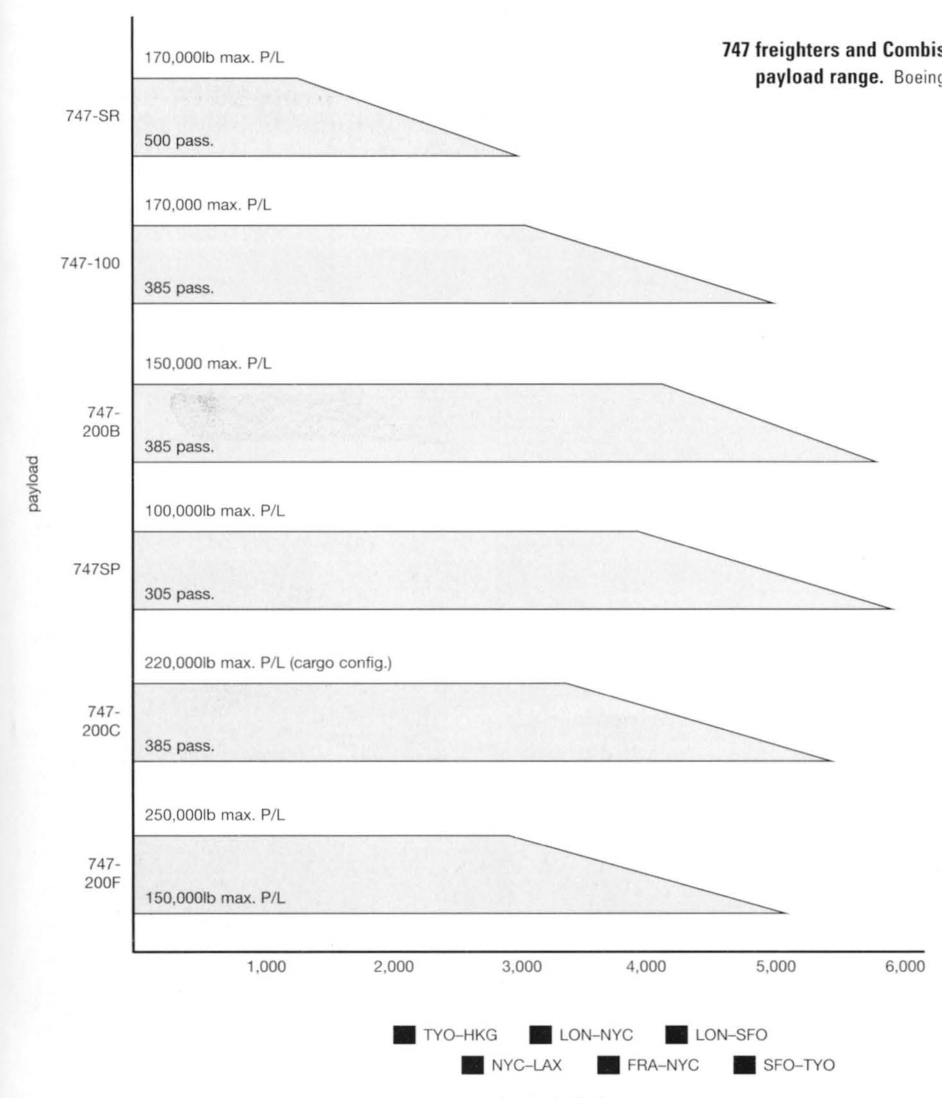
***(Opposite page, bottom)* 747-233BC C-GAGA for Air Canada, the 250th 747, is rolled out at Seattle on 30 October 1974. This aircraft, the sixth for the Canadian carrier, was the first to be produced with the optional main-deck cargo door. When delivered on 7 March 1975, it could carry 365 passengers in all-passenger configuration, or a maximum main-deck cargo load of 176 passengers and twelve cargo pallets. When this photo was taken, two 747s were being produced each month by Boeing and 747s had, since the first was rolled out on 30 September 1968, carried 74 million passengers and flown 2.6 million hours. C-GAGA was ferried via Toronto-Tucson-Marana for storage on 14 January 1999.** Boeing

Ex-Varig 747-2L5BF, VR-HMF of Air Hong Kong taxiing at Kai Tak, 27 June 1997. Graham Dinsdale

Ex-Air Afrique (TU-TAP) 747-2S4F HL7474 of Korean Air Cargo climbing out of Kai Tak on 29 April 1998. Graham Dinsdale

lease to Avianca (Aerovias Nacionales de Columbia), crashed on approach near Madrid in November 1983. An Air France -228B Combi, F-GCBC, ran off the runway at Galeao International at Rio de Janeiro, Brazil, on 2 December 1985, and was damaged beyond economical repair. And on 28 November 1987, ZS-SAS *Helderberg*, a South African Airways -244B Combi en route to Mauritius, crashed into the Indian Ocean 137 miles (220km) north-east of the island after a cargo fire.

The loss of the Avianca 283M Combi with 182 people on board on 27 November 1983 occurred late at night at the end of the flight from Paris to Madrid's Barajas Airport. The captain had over 23,000 hours' flying experience, and he and his first officer were very familiar with the airport. As the Combi reached the last part of the flight the crew were advised by air traffic that they were cleared to descend for an approach to Runway 33. At 9,000ft (2,750m) the first officer checked his ILS approach chart which gave the exact height of Barajas Airport as 1,906ft (581m). At this point the captain told his first officer to switch to the marker. His first officer did so, and gave the final approach heading and ILS localizer frequency, which the captain repeated. The first officer then said that the crossing altitude of the marker was 2,382ft (726m). This, however, was incorrect, the correct crossing altitude of the maker being 3,282ft (1,000m): the officer had transposed the first two digits, effectively putting the Combi 900ft (274m) below the safe height.



747 freighters and Combis payload range. Boeing

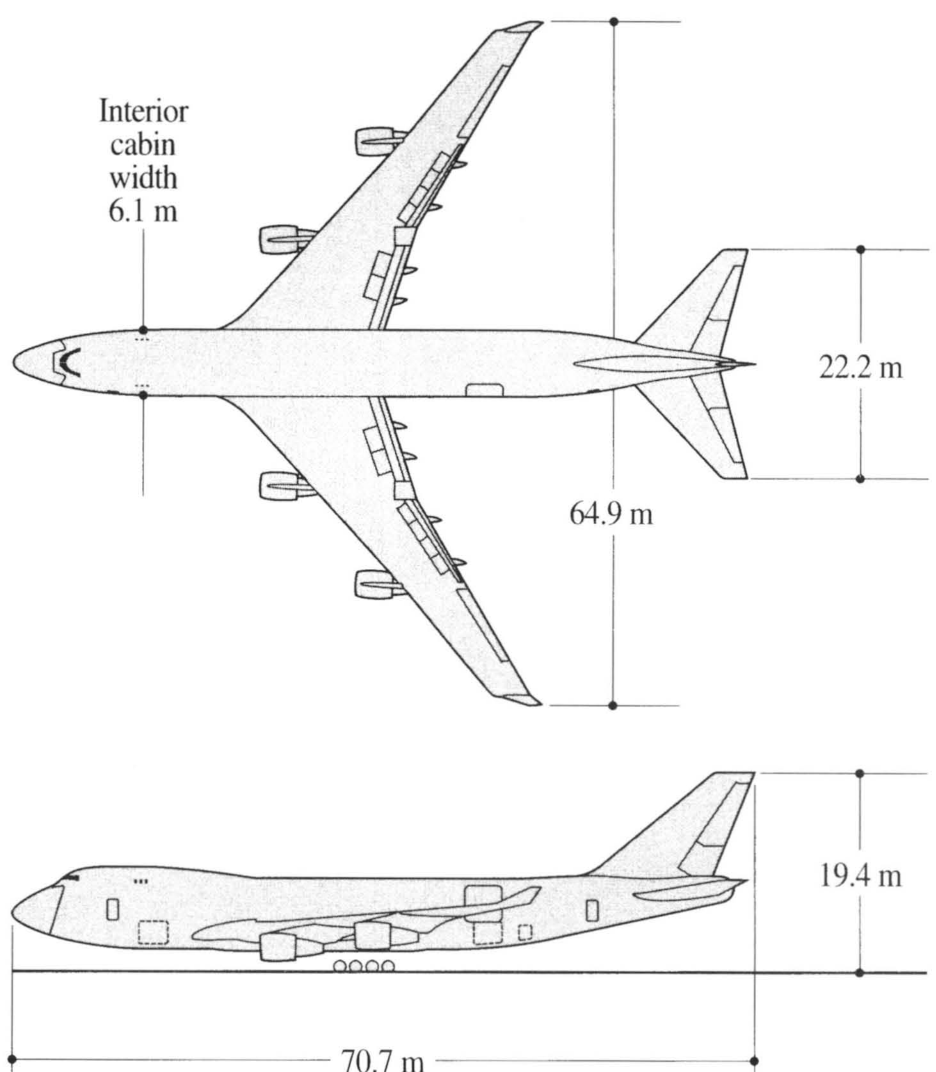
The captain accepted the incorrect height and continued on the descent. Controlled by the autopilot, the Combi descended until it was at about 80ft (24m) below the *incorrect* safe height given by the first officer. The captain, oblivious to the error, continued – and he was not even concerned when the ground proximity warning system instructed him to 'Pull up: terrain!': he discounted it, and continued as if nothing was wrong, disconnecting the autopilot and slightly reducing his rate of descent. The Combi crashed into the ground at 139 knots at an altitude of 2,249ft (685m). There was only one survivor.

ZS-SAS, the South African Airways -244B Combi which caught fire and crashed into the Indian Ocean with the loss of the crew and more than 150 passengers on 28 November 1987, highlighted several inadequate practices. The last word received was that the crew reported smoke on the flight deck, and this was borne out by wreckage recovered from the subsequent deep-sea salvage operation several months later; the board of enquiry later concluded that a freight pallet in the main deck area had caught alight, and that the fire had quickly spread to other parts of the aircraft. The smoke detectors were inadequate, and the fire-fighting equipment fitted could not hope to contain the fire. Furthermore, the enquiry concluded that the pressure lock between the cargo compartment and the main passenger cabin was incapable of preventing smoke seeping through. The enquiry's report led to a tightening-up of fire precautions, more powerful fire-fighting equipment, and the installation of higher-standard fire-resistant materials in the ceiling and side walls. Subsequently all cargo had to be transported in flame-penetration-resistant containers with built-in smoke detectors and fire-extinguishing systems.

Model 747-400 Freighter

An all-cargo version was added to the 747-400 family in 1989. The 747-400 freighter, which is equipped with a hinged nose for straight-in freight loading, can transport more cargo (249,000lb/113,000kg) further than any other commercial jet freighter. Compared to the 747-200 freighter, it has 26 tons (23,590kg) more payload capacity, a 1,380-mile (2,220km) longer range, with a 12 per cent better fuel-burn per lb of payload. This increased range and improved

(Above) **An all-cargo version was added to the 747-400 family in 1989, and Luxembourg-based airline Cargolux put the first -428F (F-GIUA) into service in November 1993. The -400 freighter, which does not have an extended upper deck (EUD), is equipped with a hinged nose for straight-in freight loading, and can transport more cargo (249,000lb/113,000kg) further than any other commercial jet freighter. 747 series freighters account for more than 30 per cent of the world's dedicated freighter fleet capability.** Boeing



General arrangement, 747-400 Freighter. Boeing

fuel-burn greatly impressed freight carrier such as Luxembourg-based Cargolux, one of Europe's largest all-freight airlines, which received the first -428 freighter (F-GIUA) on 17 November 1993. Cargolux reported that -400F operation would enable them to dispense with about 300 refuelling stops a year.

The 747-400 freighter accommodates all standard airborne pallets, including 8 × 8ft (2.4 × 2.4m) intermodel containers up to 40ft (12m) long, or special cargo up to 180ft (55m) long. It routinely carries cars, long pipe and drilling equipment, live animals, small aircraft, high-bypass-ratio aircraft engines, and heavy, outsized machinery and vehicles. The side cargo door accepts loads of up to 10ft (3m) high. Steerable automatic power-drive units rotate 20ft (6m)-long containers or pallets forward of the door, then transfer them laterally so that loads can be positioned along either side of the main deck. No manual handling is required.

CHAPTER EIGHT

Military and Multifunctional

NASA Shuttle-Carrier

On 18 July 1974 the National Aeronautics and Space Administration (NASA) obtained 747-123 N9668, the eighty-sixth 747 built, from American Airlines. After using it for wake vortex investigation, NASA sent it to Boeing in 1976 for modification as a carrier for the forthcoming space shuttle; it was subsequently designated a 'shuttle-carrier aircraft, or SCA. The aircraft, now serialled N905NA, was stripped of all airline equipment, although the original American Airlines red, white and blue striping was retained. The fuselage was reinforced to support the weight of the 150,000lb (68,040kg) shuttle, and removable large end-plate fins were added to the tail-plane to improve directional stability when carrying the orbiter. These and the modified support structures protruding from the fuselage roof reduced the 747's performance. An all-up weight limit of 710,000lb (322,060kg) was laid down. With or without the shuttle on top, the 747's crew were restricted to Mach 0.6 and 26,000ft (7,925m), or about 250 knots IAS. The JT9D-3A engines were modified to JT9D-7AH standard to increase take-off thrust to 46,900lb (21,270kg). (On 27 October 1988 NASA acquired from Boeing, N747BL, the former JAL SR-46 (JA117), the 221st 747 built, for use as a second shuttle-carrier after suitable modification.)

Two missions were planned for the SCA: carrying the shuttle aloft for initial aerodynamic testing, followed by launch into free-gliding flight; and ferrying it from the US west coast, where it is built and where it usually lands, to the launch site at Cape Canaveral in Florida. The first use was made of the SCA in February 1977 when N905NA began a three-phase flight-test programme with space shuttle *Enterprise* at NASA's Dryden Flight Research Facility at Edwards AFB, California. The shuttle was mounted on top of the SCA by being hoisted under an overhanging gantry, after which the SCA is wheeled into place beneath it. The shuttle was then lowered into the cradles on top of the SCA. The gross weight of the combination was 584,000lb (264,900kg). The three rocket motor nozzles of the shuttle were covered by a Boeing-built fairing.

In 1974 the National Aeronautics and Space Administration (NASA) obtained 747-123 N9668 from American Airlines, and after using it for wake vortex investigation, in 1976 it was modified as an SCA carrier for the space shuttle programme. Boeing

On 18 February 1977 N905NA made its first flight carrying the space shuttle Enterprise **unmanned at NASA's Dryden Flight Research Facility at Edwards AFB, California.** Boeing

After the initial taxiing tests of the 747-orbiter combination had taken place, the first flight was made on 18 February; this was with the shuttle unmanned and not to be released. A second captive phase with two crew aboard the shuttle was tested, and finally a third phase, which started on 13 August 1977, tested the shuttle's ability to be released off the 747's back. Launch procedure for the shuttle called for the 747 to climb to 25,000ft (7,620m), and when it reached 200 knots, to enter a shallow dive at full power. The separation point was reached at 240 knots, at which time the 747 pilot pulled the engines back to idle and deployed the speed brakes. When the necessary airspeed was attained, the crew of the shuttle released the latches and lifted free of the SCA. Chuck Yeager, the first man to fly faster than the speed of sound, must take the credit for proposing that the shuttle be mounted on the back of the 747 with a positive angle of attack: this helped to provide some lift, and on launching, the airflow built up quickly and enabled the shuttle to fly easily away and clear of the back of the 747.

If things went wrong and the 747 crew needed to evacuate their aircraft, they could use a chute-type slide that was installed behind the flight deck and which exited below the nose section. The exit hatch was fitted with an explosive device to blow out the door, and the crew, who would be wearing parachutes, would then have bailed out. (As another safety measure, the hydraulic system on board the 747 was fitted with close-valves to prevent all pressure being lost throughout the system if the shuttle collided with the tail as the two separated.) In the event, all the combination tests proved successful, and the crew had no call to use the precarious slide.

Iranian Air Force 747s

In 1975 the pre-revolutionary Imperial Iranian Air Force (the IIAF – later, the Iranian Islamic Air Force) acquired eleven used 747 airliners, and arranged for the then Boeing Military Aircraft Company in Wichita to militarize them. Five were 747-131s purchased from TWA, two were ex-Continental Airlines 747-124s, and four were 747-125s that Eastern Air Lines had bought from Boeing but had immediately sold to TWA. While at Wichita, all were fitted with side cargo doors, and three with Boeing in-flight refuelling booms. These received three-digit IIAF serial numbers preceded by the figure 5. In 1976, these were all replaced by four-digit numbers prefixed by 5.

In 1977 and 1978, the IIAF ordered five additional 747-2J9Fs new from Boeing, although the last of these five was never delivered, going instead to Northwest. Some of these aircraft were also adapted to carry Beech refuelling pods under the wings for the in-flight refuelling of receiver aircraft. (Originally the -2J9Fs were assigned continuing four-digit numbers, but in 1984 all but three of the IIAF 747s were given civil registrations.)

The IIAF 747s were used regularly on flights between Iran and USAF bases to pick up military stores and equipment, but all this ended in 1979 when the Shah of Iran was deposed. All the Iranian 747s were eventually disposed of, the -200s being transferred to Iran Air.

In 1975 the pre-revolutionary Imperial Iranian Air Force (IIAF; later this stood for the Iranian Islamic Air Force) acquired twelve used 747 airliners and arranged for the then Boeing Military Aircraft Company in Wichita to militarize them (5-8105(5-284), pictured). Five were -131s, purchased from TWA, three were ex-Continental Airlines -124s, and four were -125s that Eastern Air Lines had bought from Boeing but had immediately sold to TWA. While at Wichita, all were fitted with side cargo doors, and three with Boeing in-flight refuelling booms. After the Shah of Iran was deposed in 1979 all the Iranian 747s were eventually disposed of, 5-8105 being registered EP-NHR and currently, EP-SHD, operating with Saha Air Cargo. Boeing

C/No.	*Series*	*Source*	*Iranian AF Serial Nos.*
19733	-124/SCD	ex-Continental	5-289/5-8110
19734	-124/	ex-Continental	5-290*
19735	-124/SCD	ex-Continental	5-291/5-8112
20080	-125/SCD	ex-EAL/TWA	5-282/5-8103
20081	-125/SCD	ex-EAL/TWA	5-284/5-8105
20082	-125/SCD	ex-EAL/TWA	5-286/5-8107
20083	-125/SCD	ex-EAL/TWA	5-288/5-8109
19667	-131/SCD	ex-TWA	5-280/5-8101
19668	-131/SCD	ex-TWA	5-285/5-8106
19669	-131/SCD	ex-TWA	5-287/5-8108
19677	-131/SCD	ex-TWA	5-283/5-8104
19678	-131/SCD	ex-TWA	5-281/5-8102
21486	-2J9F		5-8113/EP-NHN
21487	-2J9F		5-8114/EP-NHQ
21507	-2J9F		5-8115/EP-ICB
21514	-2J9F		5-8116/EP-ICC

** not taken up*

Ex-TWA 747-131/SCD (N93102) 5-285 (5-8106) of the Imperial Iranian Air Force being refuelled in flight by IIAF 707-3JC (code-named 'Peace Station') tanker 5-241 (later 5-8301). Boeing

USAF E-4 Series

On 23 February 1973 the USAF's Electronic Systems Division awarded Boeing a $59 million fixed-price contract for two E-4A (747-200B) Advanced Airborne Command Post aircraft. These are logical successors to the various KC-135/EC-135 aircraft used to support the National Emergency Airborne Command Post (NEACP) – known as 'Kneecap' – as flying command posts. The greater capacity of the 747 allows the carriage of more equipment and a larger battle staff, plugs built-in 'hardness' features designed to protect the aircraft and its equipment from the effects of nuclear blasts. A third E-4A was ordered in the early summer of 1973 at a cost of $27.7 million. The fourth and final aircraft, a E-4B, with more advanced engines and equipment, was contracted in December at a cost of $39 million.

All three E-4As had their command, control and communications equipment fitted by E-Systems (later part of Raytheon). As an interim measure this was equipment removed from the EC-135 aircraft. 73-1676, the first of three E-4As, was powered by JT9D engines, and first flew on 13 June 1973; it was delivered to Andrews AFB, Maryland, on 16 July, after which much of the classified equipment was installed. 73-1677, the second E-4A, first flew on 11 September, and was delivered on 3 October; and 74-00787, the third, which was also the first production 747 to be powered by GE CF6 engines, first flew on 6 June 1974 and was delivered on 15 October. Later, the first two E-4As were re-engined with the CF6, and later still, with the more powerful 52,500lb (23,814kg)-thrust CF6-50E2.

C/No.	Series	Unit	Serial No.
20682	E-4A	USAF/1st ACCCS/55th Wing	73-1676
20683	E-4A	USAF/1st ACCCS/55th Wing	73-1677
20684	E-4A	USAF/1st ACCCS/55th Wing	74-0787
20949	E-4B	USAF/1st ACCCS/55th Wing	75-0125

A fourth aircraft (75-0125) was made on the original E-4A order, but it incorporated many refinements, such as nuclear thermal shielding (hardening), including electromagnetic pulse, additional generators for increased electrical capacity for the equipment, and a larger battle staff. It first flew on 29 April 1975, and was delivered to the USAF on 4 August as an E-4B with less than full equipment. (This was installed over several years by organizations contracted to the USAF Oklahoma City Air Logistics Center.) The fully equipped E-4B was redelivered to the Air Force (SAC) on 21 December 1979, and it flew its first operational mission in March 1980. All three E-4As were subsequently upgraded to E-4B standard, with the first redelivered to the Air Force on 15 July 1983.

The E-4B has increased internal fuel for missions in excess of twelve hours' duration, but it can also be refuelled in flight to extend endurance to seventy-two hours. The increased fuel load, and other modifications, give the aircraft an all-up gross weight of 800,000lb (362,870kg). The E-4B has a 1,200-kilovolt-amp electrical system, compared with the 240-kilovolt-amp systems on the standard 747s, driven by two 150-kilovolt-amp generators mounted on each of the engines. Altogether, ninety-four crew members can be carried on three decks. The upper deck contains the flight deck and a 330sq ft (30.7sq m) flight-crew rest area, while the 185ft (56m) long main deck is divided into compartments for an NCA area, briefing and conference rooms, a battle-staff work-area for up to thirty crew, communications and technical control centres, and a crew rest area.

As first delivered, the E-4B was outwardly indistinguishable from the E-3As, but when the super-high-frequency (SHF) satellite link was installed, a large and distinctive blister was added to the top of the fuselage at the rear of the upper deck to house the dish antennae. At the opposite end of the radio frequency range is the dual very-low-frequency (VLF) and low-frequency (LF) communications equipment which uses two trailing-wire aerials, the longer of which is 5 miles (8km) long when fully deployed. (The forward and rear lobes on board the aircraft house electronic equipment, a maintenance workshop and a small station in the tail for the VLF antenna winch operator.) Altogether, the aircraft has thirteen external communications systems operating through no fewer than forty-six different antennae.

Most of the functions that can be performed in the air relative to communication with ground facilities throughout the world can be performed while the E-4B is on the ground when appropriate connections are made to the aircraft. The improved satellite communications system, and communications processing equipment, have anti-jam features and support operations in a nuclear environment over extended ranges. The E-4B is capable of tying into commercial telephone networks, and has the potential to be used for radio broadcasts to the general population. In recent years improvements have included a data-processing capability and more survivable command, control and communications' equipment, including initial Milstar modification. All four E-4Bs are operated by the 55th Wing, Air Combat Command, and the main operating base is currently Offut AFB, Nebraska.

USAF C-Series

From 1985 to December 1989, eighteen Pan Am 747s (fourteen -100s and four -200Bs, each converted at a cost of up to

E-4B 75-0125 operated by the 1st ACCCS, 55th Wing. The E-4B first flew on 29 April 1975, with delivery to the USAF on 4 August, with less than full equipment. This was installed over several years by organizations contracted to the USAF Oklahoma City Air Logistics Center. The fully equipped E-4B was redelivered to the Air Force (SAC) on 21 December 1979, and its first operational mission was flown in March 1980. Boeing

***(Top)* The E-4B has increased internal fuel for missions in excess of twelve hours' duration, but it can also be refuelled in flight to extend endurance to seventy-two hours. All three E-4As were subsequently upgraded to E-4B standard.** Boeing

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C/No.	*Series*	*Unit*	*Serial No.*
23824	C-25A	89th ALW	86-8800/82-8000
23825	C-25A	89th ALW	86-8900/92-9000

C/No.	*Series*	*Operator*
21652	SP-68 HZ-HM1	Saudi Royal flight RSAF/1 Sqn
21785	SP-27 A40-SO	Govt of Oman
21961	SP-31 A6-SMR	Govt of Dubai (op by Dubai Air Wing)
21963	SP-31 A6-SMM	Govt of UAE (op by Dubai Air Wing)
22750	SP-68 HZ-AIJ	Saudi Royal Flight
23610	SP-Z5 A6-ZSN	Govt of Abu Dhabi

$20 million by Boeing Wichita) were made available to the Civil Reserve Air Fleet (CARF) as a ready reserve of heavy-lift transports (C-19A) in times of national emergency. The Air Force contracted with Pan American World Airways to modify these 747s with side cargo doors, reinforced main-deck flooring, and a cargo distribution system, all of which added 13,000lb (5,900kg) to the empty weight of the aircraft. Because of a corresponding reduction in payload, the USAF paid compensation to Pan Am during commercial passenger operations. The first C-19A conversion (Air Force serial numbers were not assigned) was completed on 31 May 1985. When the aircraft were no longer used, Boeing-Wichita subsequently converted five of them to full freighter configuration.

Two 747-2G4Bs powered by four CF6-80C2B1s (F103-GE-102s), each developing 56,750lb (25,740kg) of thrust, were purchased by the DoD under the designation VC-25A, to replace the two former primary and back-up VC-137Cs (707-320C) that had served as presidential aircraft, the first since 12 October 1962, and the other since 1972. The first VC-25A was rolled out in September 1989, and both aircraft were delivered to the 89th Airlift Wing at Andrews AFB, Maryland, in August and December 1990. The VC-25As had a Bendix Aerospace EFIS-10 electronic flight instrument system and state-of-the-art on-board world-wide communications equipment, two galleys, and an emergency medical facility. A pair of self-contained air-stairs were located on the left side, and a built-in baggage loader on the right side. Together with a second Garrett GTCP331-200 auxiliary power unit (APU) in the tail, they allowed the aircraft to be practically self-sufficient, and reduced the need for ground-support equipment. Despite their long range (7,140 miles/11,488km), the VC-25As could also be refuelled in the air. Each carried a crew of twenty-three, and could carry up to seventy passengers. Maximum take-off weight on a long-range mission was 803,700lb (364,560kg).

In addition, six 747SP series have been, or are being used in a military or military-operated role by the countries of Abu Dhabi, Oman, Saudi Arabia, United Arab Emirates (UAE) and Dubai.

Military Derivative Proposals

Apart from the E-4, Boeing saw additional potential for the 747 as a military tanker, transport aircraft, and even as a missile launcher. During the height of the Cold War, data was prepared and service trials were conducted, but not one aircraft was ever purchased by the USAF, although the Imperial Iranian Air Force did show some interest in the 747 in the joint freighter-tanker role, and at least two were so converted. Boeing saw the 747 as a tanker that could refuel B-52 bombers with 230,000lb (104,330kg) of fuel after both aircraft had flown 4,600 statute miles (7,400km). This would have added about 2,990 miles (4,810km) more range than if the Stratofortresses had been refuelled by a KC-135. A 747 was modified with a flying-boom, and trials involving dry hook-ups took place with a B-52, SR-71 Blackbird and an F-111 as the receiver aircraft. The trials were funded by the US military and were successful, but nothing came of the 747 tanker project.

Nothing came of the proposed MC747 concept which appeared in 1972, either: this promoted the idea that the -200F could be modified as a launch platform for four Minuteman intercontinental ballistic missiles (ICBMs). The missiles would have been released backwards or forwards from a bay in the aft section 46, modified with bomb-bay doors. When dropped facing backwards either the MC747 would have to be flying away from the target, or the missiles would rotate up and over the aircraft to head for their target. If they were launched facing forwards, then they would drop underneath the 747 and ignite before streaking towards their target 5,000ft (1,500m) ahead of the aircraft.

Not surprisingly perhaps, the MC747 concept never left the drawing board. Neither did Boeing's other equally ambitious bomb-carrying versions, where it was calculated that up to seven 57,000lb (25,855kg) missiles could be carried in bomb-bays forward and aft, or that two 200,000lb (90,720kg) missiles could be dropped from a bomb-bay more than 65ft (20m) long. An air-launched, cruise missile (ALCM), carrier version was proposed whereby the 747 would carry forty-three ALCMs and launch them from the rear of the aircraft after they had been loaded onto carriage racks through the nose door. However, this scenario never reached fruition; not did another proposal, whereby the ALCMs would be launched from rotary launchers or stack racks, like those used on the B-52.

More 747 Military Proposals

In view of the long-standing problems with the C-5A, Boeing proposals in the late 1970s and early 1980s to use the 747-200F as an airlifter for the USAF seemed to have merit, especially when fatigue cracks were found in the Galaxy's wings. Boeing even developed a special nose-jack to reduce the sill height of the nose door by 6 to 10ft (2 to 3m) off the ground to enable tanks and vehicles to be loaded and offloaded. The device was successfully tested in 1980 using a Flying Tigers -200F, but the US government, probably acutely embarrassed by the vast fortune it had already spent on the much-maligned Galaxy, did not show any tangible interest in the 747 transport. After contracting Lockheed to develop new wings for the C-5A, in1982 the military ordered fifty C-5B versions instead.

In the early 1990s Boeing saw another opportunity to promote the 747 transport

Two 747-2G4Bs (C/nos. 23824/5) were purchased by the DoD under the designation VC-25A, to replace the two former primary and back-up VC-137Cs that had served as presidential aircraft, one since 12 October 1962, and the other since 1972. The first VC-25A (82-8000, formerly 86-8800) was rolled out in September 1989. This and the second VC-25A (92-9000, formerly 86-8900) were delivered to the 89th Airlift Wing at Andrews AFB, Maryland, on 23 August and 20 December 1990 respectively. Mick Jennings

when cost-overruns on the McDonnell Douglas C-17 Globemaster III programme persuaded the Department of Defense to invite proposals for an off-the-shelf non-developmental airlift alternative (NDAA). No fewer than eleven aerospace companies came up with proposals for airlifter versions of existing aircraft. Boeing proposed a P&W 4056-powered 747-200F airlifter, designated the C-33A, which had an increased weight of 920,000lb (417,300kg) and an 8,970-mile (14,430km) range. Their bid was helped in 1991–92 during Operation *Desert Shield* and Operation *Desert Storm*, which saw a massive increase in 747 cargo operations. During and after the Gulf War, 747s flew 3,700 missions, transporting no fewer than 644,000 troops and 220,000 tons of equipment and supplies. In 1995 Boeing and Pratt & Whitney's joint PW4056-powered C-33A proposal emerged successful from all of the competitors – but none of the new aircraft was ordered. Instead, the DoD maintained the *status quo* with the C-17 Globemaster III – which, ironically, is now produced by Boeing since its take-over of McDonnell Douglas.

The YAL-1A Project

Because of the US military's experience gained in the Gulf War, when Patriot missiles were launched to intercept theatre ballistic missile such as the Soviet-built Scud, the DoD sought alternative methods whereby incoming missiles could be destroyed by an airborne laser (ABL) defence system. In 1994, Boeing (with TRW, manufacturers of the chemical oxygen iodine laser (COIL), and Lockheed-Martin, who build the optics and detectors) became one of two consortiums selected to study ways of implementing such a system and mounting it in a turret in the nose of an aircraft.

The platform the consortium chose was a prototype derivative of the 747-400F freighter, called the YAL-1A. The life potential of an aircraft of this size has immediate benefits for the project in that it can carry sufficient oxygen and iodine for up to thirty bursts of five seconds each. The range of the COIL (180–360 miles/290–580km), and the accuracy of the optics and detectors (which can lock onto a missile as it enters the boost phase during the first 30–140 seconds of flight) are such that the YAL-1A can fly at altitudes in excess of 40,000ft (12,200m), several hundred miles from its target, and still destroy in-flight missiles within seconds of them being launched. Laser tests carried out showed that a five-second burst of energy fired at the missile by the COIL so soon after take-off would cause the propellant tanks to explode and thus scatter the debris in the vicinity of the launch site, an ideal deterrent.

In November 1996 the Boeing-TRW-Lockheed-Martin proposal was declared the winner of the initial 6½ year $1.1 billion contract covering the building of a YAL-1A, and the mounting and test-firing of the ABL. The DoD expected that the first test to destroy a theatre ballistic missile would take place by late 2002. If the first part of the programme proved successful, Boeing anticipated winning a $4.5 billion follow-on contract to build a further six AL-1A production aircraft, the first scheduled to be fully operational by 2006, with the rest in service by 2008. This number of aircraft was arrived at because of the need, in times of international crisis, for at least one AL-1A to be airborne at any one time.

CHAPTER NINE

'Megatop'

The 747-400 Series

By the early 1980s Boeing's seemingly unconquerable 747 was under threat from market forces, and it must have seemed to many in the industry that the 747 had reached the end of its development. By 1984 production stood at just one 747 a month, down from seven a month in 1979–80. In the United States and Europe, McDonnell Douglas and Airbus Industries respectively, were emerging as strong contenders vying for the crown that Boeing had worn for almost twenty years. The MD-11, a much bigger and much modernized version of the DC-10-30/40 series, made its appearance at the 1985 Paris Air Show. Airbus was also fast developing its range of state-of-the-art, long-range, high-capacity A330/340 aircraft. Boeing countered these very competitive high-tech designs with new, twin-engined aircraft of their own, but while the 757 and 767 kept pace with the latest avionics, lighter carbon-composite materials, higher-aspect ratio wings and systems, its elder statesman, the 747, still relied heavily on electro-mechanical instruments and systems little changed from the late 1960s. It was obvious from the lessons learned with the launch of the 747-300 that what the airlines wanted was not simply an 'advanced series 300', which evolved in 1984, but rather, a radically new approach with modern avionics, longer range and higher capacity.

In May 1985, Boeing announced the development of the new model 747-400, an advanced and greatly improved long-range version of the Model 747-300. Apart from a quantum leap in technology, if the 747 was to remain competitive against the all-comers, Boeing recognized the need greatly to improve the aircraft interior, range, fuel-burn and operating costs. These were daunting targets to apply to an aircraft design that was almost twenty years old. Replacing the interior with the latest fire-resistant materials, upping the fuel capacity and adopting the latest engines would go a long way to achieving many of these goals, but initially, Boeing baulked at changing the flight deck completely, choosing instead to retain the original electro-mechanical instrumentation and to keep the same autopilot. At first, Boeing's whole approach to the -400 was to avoid wholesale change, particularly on the flight deck, principally to help minimize aircrew retraining. At first therefore, only a reduction in the number of conventional electro-mechanical instruments took place. Boeing were greatly influenced in this approach by Cathay Pacific, one of the launch customers from a consultative group formed by Boeing which also included British Airways, KLM, Lufthansa, Northwest, Qantas and Singapore Airlines.

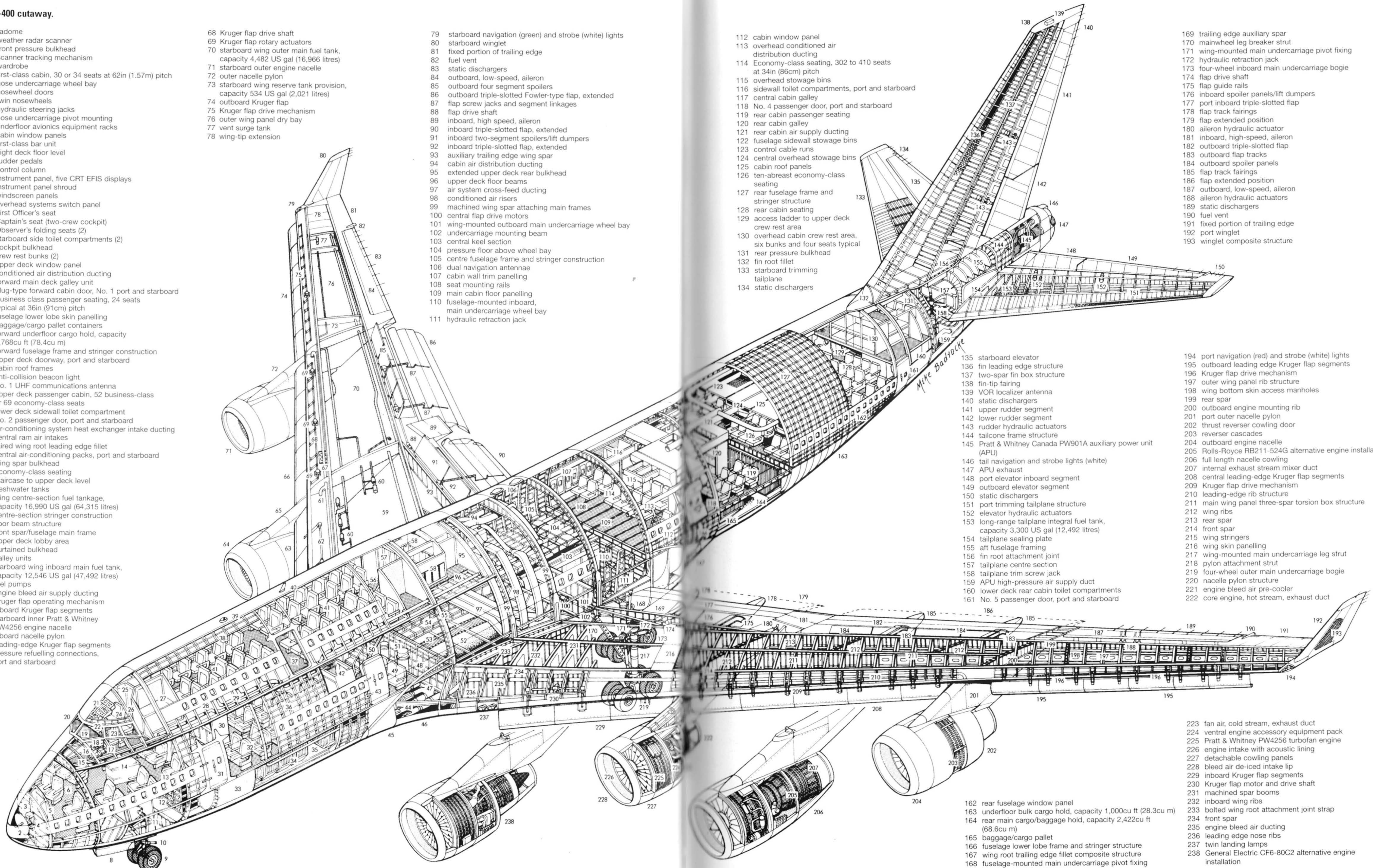
Boeing's decision to utilize technology used on the 757 and 767 twins changed in 1985 after pressure from most of the other airlines in the consultative group who by now were enjoying significant technological advances in their operation of the advanced Airbus A320 aircraft, which used the latest digital avionics. They persuaded Boeing to update the 747-400 with the latest 'glass' or digital avionics, including improved EFIS (electronic flight instrument systems) displays with their fault warnings and corrective actions, collision avoidance, datalink, wind-shear warning, 4D navigation (a calculation of whether or not the -400 can reach a certain altitude by a certain navigational waypoint) and digital electronic engine control (known as 'power by wire'). Out went the flight engineer's panel, and an all-new flight deck operated by a two-man crew was adopted. (Back in the early days of 747 operation, Pan Am had a system whereby pilots, after retiring as such at the mandatory age of sixty, could continue flying as flight engineers.) The 400 pilots and engineers and 200 ground staff who visited the 747-400 flight simulator were almost unanimous in their praise for the revised and much simpler instrument layout, and finally, even Cathay Pacific was won over.

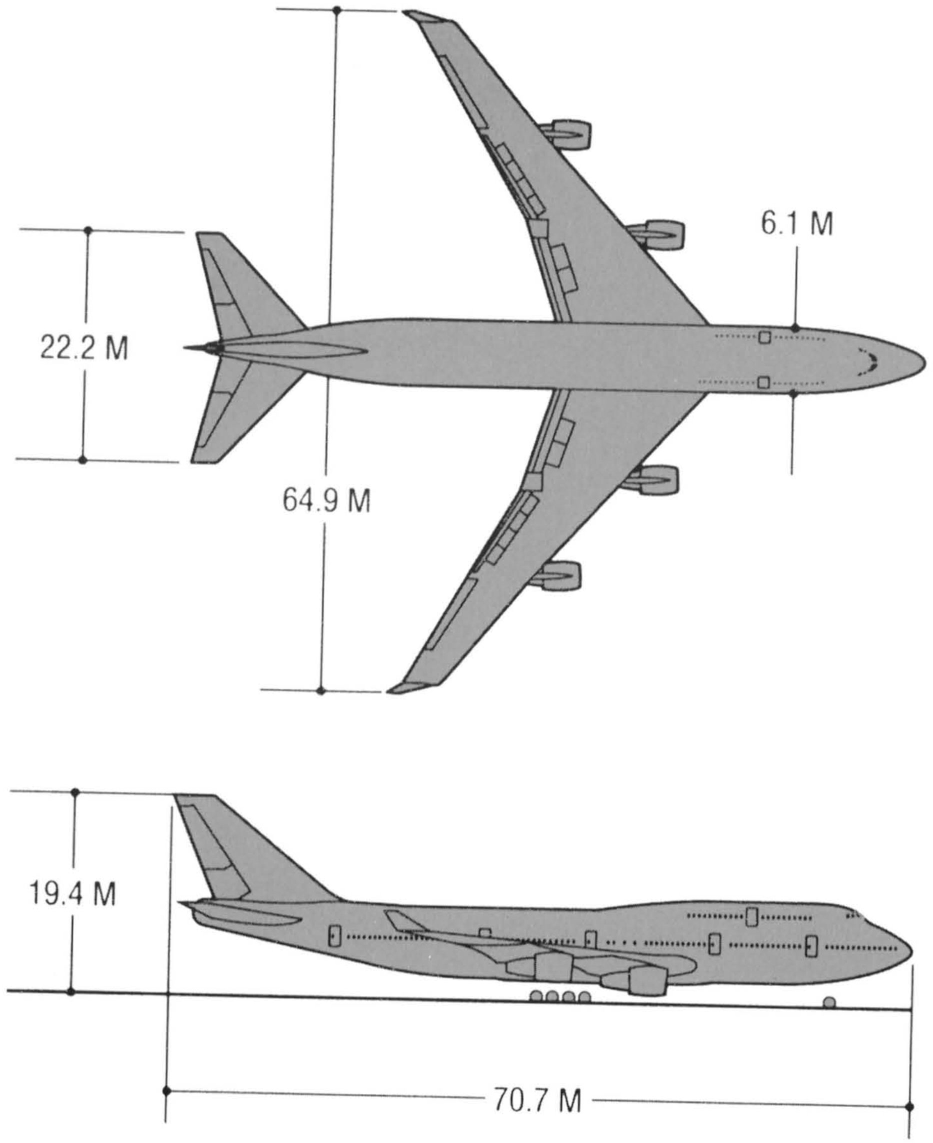
A significant weight-saving of some 4,200lb (1,900kg) has been achieved through the use of new, lighter, high-strength aluminium-lithium alloys with improved fatigue life incorporated in the upper and lower skins of the wing torsion box, stringers and lower-spar chords. A further 1,800lb (816kg) was saved by the replacement, on the -400's huge five-truck, eighteen main landing-gear wheels, of steel brakes with BF Goodrich carbon brakes and new wider wheels (the sixteenth version of the 747 wheel, with the diameter increased by 2in (5cm) to 22in (55cm), to house the new brakes) with low profile tyres so that the same overall diameter of 49in (123cm) could be maintained. All areas of the structure which have previously been prone to fatigue cracks have been strengthened, the large front end having thicker frame, skins and doublers to obviate expensive repair procedures. Metal flooring previously used in the passenger cabin has been replaced by light, tough graphite floor panels. Corrosion protection is further improved by white epoxy paint in the under-floor areas, especially in the areas below and around the toilets and galleys.

The rudder has an increase of five degrees movement to 30 per cent over earlier 747s, and new rudder actuators decrease the runway minimum control speed by 10 knots. The large epoxy composite fairing which covers the join between the fuselage and the wing has been recontoured to reduce drag. Unladen wingspan has been increased to 211ft 5in (64.5m) by the use of upward-pointing 6ft-(1.8m-) high winglets with a sweep back of 60 degrees, canted out at an angle of 22 degrees. (When the -400 is fully fuelled, due to the flexible wing structure and the outward-canted winglets, the span

747-400 cutaway.

1 radome
2 weather radar scanner
3 front pressure bulkhead
4 scanner tracking mechanism
5 wardrobe
6 first-class cabin, 30 or 34 seats at 62in (1.57m) pitch
7 nose undercarriage wheel bay
8 nosewheel doors
9 twin nosewheels
10 hydraulic steering jacks
11 nose undercarriage pivot mounting
12 underfloor avionics equipment racks
13 cabin window panels
14 first-class bar unit
15 flight deck floor level
16 rudder pedals
17 control column
18 instrument panel, five CRT EFIS displays
19 instrument panel shroud
20 windscreen panels
21 overhead systems switch panel
22 First Officer's seat
23 Captain's seat (two-crew cockpit)
24 Observer's folding seats (2)
25 starboard side toilet compartments (2)
26 cockpit bulkhead
27 crew rest bunks (2)
28 upper deck window panel
29 conditioned air distribution ducting
30 forward main deck galley unit
31 plug-type forward cabin door, No. 1 port and starboard
32 Business class passenger seating, 24 seats typical at 36in (91cm) pitch
33 fuselage lower lobe skin panelling
34 baggage/cargo pallet containers
35 forward underfloor cargo hold, capacity 2,768cu ft (78.4cu m)
36 forward fuselage frame and stringer construction
37 upper deck doorway, port and starboard
38 cabin roof frames
39 anti-collision beacon light
40 No. 1 UHF communications antenna
41 upper deck passenger cabin, 52 business-class or 69 economy-class seats
42 lower deck sidewall toilet compartment
43 No. 2 passenger door, port and starboard
44 air-conditioning system heat exchanger intake ducting
45 ventral ram air intakes
46 faired wing root leading edge fillet
47 ventral air-conditioning packs, port and starboard
48 wing spar bulkhead
49 Economy-class seating
50 staircase to upper deck level
51 freshwater tanks
52 wing centre-section fuel tankage, capacity 16,990 US gal (64,315 litres)
53 centre-section stringer construction
54 floor beam structure
55 front spar/fuselage main frame
56 upper deck lobby area
57 curtained bulkhead
58 galley units
59 starboard wing inboard main fuel tank, capacity 12,546 US gal (47,492 litres)
60 fuel pumps
61 engine bleed air supply ducting
62 Kruger flap operating mechanism
63 inboard Kruger flap segments
64 starboard inner Pratt & Whitney PW4256 engine nacelle
65 inboard nacelle pylon
66 leading-edge Kruger flap segments
67 pressure refuelling connections, port and starboard
68 Kruger flap drive shaft
69 Kruger flap rotary actuators
70 starboard wing outer main fuel tank, capacity 4,482 US gal (16,966 litres)
71 starboard outer engine nacelle
72 outer nacelle pylon
73 starboard wing reserve tank provision, capacity 534 US gal (2,021 litres)
74 outboard Kruger flap
75 Kruger flap drive mechanism
76 outer wing panel dry bay
77 vent surge tank
78 wing-tip extension
79 starboard navigation (green) and strobe (white) lights
80 starboard winglet
81 fixed portion of trailing edge
82 fuel vent
83 static dischargers
84 outboard, low-speed, aileron
85 outboard four segment spoilers
86 outboard triple-slotted Fowler-type flap, extended
87 flap screw jacks and segment linkages
88 flap drive shaft
89 inboard, high speed, aileron
90 inboard triple-slotted flap, extended
91 inboard two-segment spoilers/lift dumpers
92 inboard triple-slotted flap, extended
93 auxiliary trailing edge wing spar
94 cabin air distribution ducting
95 extended upper deck rear bulkhead
96 upper deck floor beams
97 air system cross-feed ducting
98 conditioned air risers
99 machined wing spar attaching main frames
100 central flap drive motors
101 wing-mounted outboard main undercarriage wheel bay
102 undercarriage mounting beam
103 central keel section
104 pressure floor above wheel bay
105 centre fuselage frame and stringer construction
106 dual navigation antennae
107 cabin wall trim panelling
108 seat mounting rails
109 main cabin floor panelling
110 fuselage-mounted inboard, main undercarriage wheel bay
111 hydraulic retraction jack
112 cabin window panel
113 overhead conditioned air distribution ducting
114 Economy-class seating, 302 to 410 seats at 34in (86cm) pitch
115 overhead stowage bins
116 sidewall toilet compartments, port and starboard
117 central cabin galley
118 No. 4 passenger door, port and starboard
119 rear cabin passenger seating
120 rear cabin galley
121 rear cabin air supply ducting
122 fuselage sidewall stowage bins
123 control cable runs
124 central overhead stowage bins
125 cabin roof panels
126 ten-abreast economy-class seating
127 rear fuselage frame and stringer structure
128 rear cabin seating
129 access ladder to upper deck crew rest area
130 overhead cabin crew rest area, six bunks and four seats typical
131 rear pressure bulkhead
132 fin root fillet
133 starboard trimming tailplane
134 static dischargers
135 starboard elevator
136 fin leading edge structure
137 two-spar fin box structure
138 fin-tip fairing
139 VOR localizer antenna
140 static dischargers
141 upper rudder segment
142 lower rudder segment
143 rudder hydraulic actuators
144 tailcone frame structure
145 Pratt & Whitney Canada PW901A auxiliary power unit (APU)
146 tail navigation and strobe lights (white)
147 APU exhaust
148 port elevator inboard segment
149 outboard elevator segment
150 static dischargers
151 port trimming tailplane structure
152 elevator hydraulic actuators
153 long-range tailplane integral fuel tank, capacity 3,300 US gal (12,492 litres)
154 tailplane sealing plate
155 aft fuselage framing
156 fin root attachment joint
157 tailplane centre section
158 tailplane trim screw jack
159 APU high-pressure air supply duct
160 lower deck rear cabin toilet compartments
161 No. 5 passenger door, port and starboard
162 rear fuselage window panel
163 underfloor bulk cargo hold, capacity 1,000cu ft (28.3cu m)
164 rear main cargo/baggage hold, capacity 2,422cu ft (68.6cu m)
165 baggage/cargo pallet
166 fuselage lower lobe frame and stringer structure
167 wing root trailing edge fillet composite structure
168 fuselage-mounted main undercarriage pivot fixing
169 trailing edge auxiliary spar
170 mainwheel leg breaker strut
171 wing-mounted main undercarriage pivot fixing
172 hydraulic retraction jack
173 four-wheel inboard main undercarriage bogie
174 flap drive shaft
175 flap guide rails
176 inboard spoiler panels/lift dumpers
177 port inboard triple-slotted flap
178 flap track fairings
179 flap extended position
180 aileron hydraulic actuator
181 inboard, high-speed, aileron
182 outboard triple-slotted flap
183 outboard flap tracks
184 outboard spoiler panels
185 flap track fairings
186 flap extended position
187 outboard, low-speed, aileron
188 aileron hydraulic actuators
189 static dischargers
190 fuel vent
191 fixed portion of trailing edge
192 port winglet
193 winglet composite structure
194 port navigation (red) and strobe (white) lights
195 outboard leading edge Kruger flap segments
196 Kruger flap drive mechanism
197 outer wing panel rib structure
198 wing bottom skin access manholes
199 rear spar
200 outboard engine mounting rib
201 port outer nacelle pylon
202 thrust reverser cowling door
203 reverser cascades
204 outboard engine nacelle
205 Rolls-Royce RB211-524G alternative engine installation
206 full length nacelle cowling
207 internal exhaust stream mixer duct
208 central leading-edge Kruger flap segments
209 Kruger flap drive mechanism
210 leading-edge rib structure
211 main wing panel three-spar torsion box structure
212 wing ribs
213 rear spar
214 front spar
215 wing stringers
216 wing skin panelling
217 wing-mounted main undercarriage leg strut
218 pylon attachment strut
219 four-wheel outer main undercarriage bogie
220 nacelle pylon structure
221 engine bleed air pre-cooler
222 core engine, hot stream, exhaust duct
223 fan air, cold stream, exhaust duct
224 ventral engine accessory equipment pack
225 Pratt & Whitney PW4256 turbofan engine
226 engine intake with acoustic lining
227 detachable cowling panels
228 bleed air de-iced intake lip
229 inboard Kruger flap segments
230 Kruger flap motor and drive shaft
231 machined spar booms
232 inboard wing ribs
233 bolted wing root attachment joint strap
234 front spar
235 engine bleed air ducting
236 leading edge nose ribs
237 twin landing lamps
238 General Electric CF6-80C2 alternative engine installation





747-400 general arrangement.

Specification – 747-400	
Powerplant:	Four 56,000lb (25,400kg) Pratt & Whitney 4056, 57,900lb (26,300kg) General Electric CF6-80C2B1F or 58,000lb (22,700kg) Rolls-Royce RB211-524G.
Weights:	Empty 391,000–393,000lb (177,400–178,300kg); gross 800,000–870,000lb (362,900–394,600kg).
Dimensions:	Length 231ft 10in (70.65m); height 63ft 5in (19.50m); wingspan 211ft 5in (64.5m)/213ft (65m) fully fuelled; wing area 5,650sq ft (525sq m).
Performance:	Cruising speed 612mph (985km/h) Ceiling 45,000ft (13,700m) Range 8,400 miles (13,500km).
Capacity:	496 passengers (typical), 630 (maximum).

actually grows by almost 2ft/0.6m to 213ft/64.9m!) The new winglets, which are graphite (carbon-fibre and epoxy honeycomb sandwich skin) increase the aspect ratio of the wing, thereby reducing induced drag and increasing the range of the aircraft by a calculated 3 per cent, or a 7 per cent fuel consumption reduction per passenger mile. This also aids the -400's take-off characteristics and permits higher cruising altitudes to be flown. To further improve take-off and landing performance, an additional leading-edge flap is fitted to the wing extension.

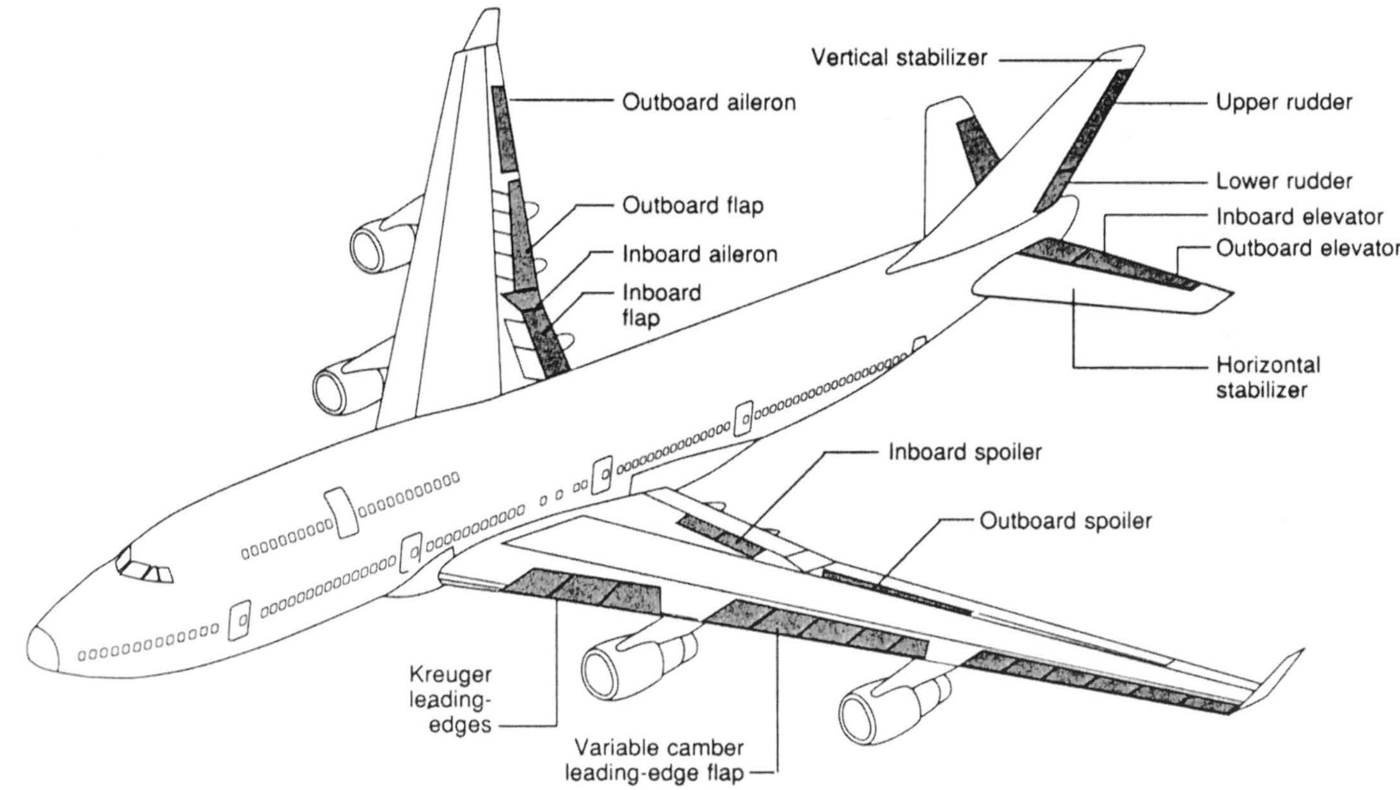
Powerplants

The improvements to the 747-400 include more powerful engines with up to 58,000lb- (26,300kg-) thrust , with a choice of three powerplants in four versions: the Pratt & Whitney PW4056, which utilizes single crystal turbine blades; the 58,000lb-thrust General Electric CF6-80C2B1F; or the 58,000lb-thrust Rolls-Royce RB211-524G/60,000lb- (27,200kg-) thrust -5224H. Since 1983 all three engines have reduced fuel-burn by 5–10 per cent, and each one is capable of full authority digital engine control (FADEC). To further increase range, by 403 statute miles (650km), an additional 3,300 US gallons (12,490 litres) of fuel can be carried in new tanks between the front and rear spars in the horizontal stabilizer (tail-plane). The -400 can carry more than 57,000 gallons (215,745 litres) of fuel and over 400 passengers in excess of 8,050 statute miles (13,000km) some 1,150 statute miles (1,850km) further than the -300.

Depending on engines and other variables, the gross weight of the 747-400 ranges from 800,000 to 850,000lb (362,900 to 385,560kg) with an option offered to 870,000lb (394,600kg). Thanks to the added fuel, the more fuel-efficient engines and the new wing-tips, the 747-400 has a range of up to 8,400 miles (13,500km). With Pratt & Whitney PW4056 engines, 412 passengers and baggage, and required fuel reserves, the range is 7,945 statute miles (12,784km). With Rolls-Royce RB.211-524Hs, up to 426 passengers and 37,400lb (17.1 tonnes) of cargo, the range is 7,178 miles (11,485km).

The 747-400's range makes possible non-stop service with typical full (420) passenger, three-class payload on such routes as London–Tokyo, Singapore–London, and Los Angeles–Sydney.

Flight-control features.



Interior Design

Interiors of the 747-400 have been redesigned to improve passenger convenience and appeal. Ceiling and side-wall panels have been recontoured with new, lighter-weight materials that provide an open, airy look. Passenger stowage capacity has grown to 15.9cu ft (0.45cu m) in each 60in (152cm) outboard stowage bin, or 2.95cu ft (0.082cu m) per passenger. New laminate materials, phenolic glass or carbon composite, able to withstand a heat release of 65W/m sq, have replaced epoxy/glass for partitions, doors, closets, galleys, toilet walls and major surfaces. A new thermoplastic blend in place of polycarbonates reduces smoke and toxicity levels in the event of fire, and upper-deck ceiling panels are made of improved polyester and phenolic sheet-moulding materials instead of standard polyester.

Interior flexibility permits airline operators to relocate class dividers and galley and toilet modules more quickly to serve market requirements. Toilet installation is simplified by a vacuum waste system, and 2in- (5cm-) diameter waste pipes running through the length of the main cabin floor, with an extension to the upper deck, enables airlines to choose from up to 121 possible toilet positions around the cabin. (Waste is collected in four tanks – two holding 85 gallons (386 litres) each and two holding 65 gallons (296 litres) each – at the rear of the belly.) Thanks to a number of utility hook-ups, airlines can also locate their galleys in up to twelve different areas, offering a total of 157 possible locations. These 'quick change features' allow major rearrangements within forty-eight hours, while seats and compartments can be changed overnight. A revised -400 air distribution system increases the main-deck cabin air-distribution zones from three to five, and ventilation rates can be regulated based on passenger density in each zone.

Crew rest is a new flight-deck feature, the dedicated flight-crew rest area with two bunks, and the décor of the flight deck having been enhanced, while the aft-adjustment of seats and stowage has been increased. For the first time on any airliner, an optional overhead cabin crew rest area uses space in the rear of the fuselage above the aft toilets. This area, which can be configured for eight bunks and two seats, provides privacy as well as comfort for off-duty flight attendants. By using this compartment, ten more profit seats are available on the main deck of the aircraft. (The crew-rest module introduced at the rear of the -300 cabin will take up twenty passenger seats.)

A new Pratt & Whitney Canada (P&WC) 1,450hp auxiliary power unit (APU) was chosen to replace the earlier Garrett (Allied Signal) APU. The PW901A APU, which drives two generators to produce a total of 180 kilovolt-amps, provides an estimated 35 to 40 per cent reduction in fuel consumption (saving an airline an estimated $125,000 per annum), better air pressurization performance on hot days, higher electrical output and reduced noise levels over the prior APU. These units, mounted in the rear fuselage of 747s, supply pressurized air for air conditioning and engine starting while the aircraft is on the ground, plus electrical power to operate lights and other requirements during stops. The new APU can also be retrofitted to earlier 747s.

For the first time on any airliner, an optional, overhead cabin-crew rest area in the 747-400 uses space in the rear of the fuselage above the aft toilets. This area, which can be configured for eight bunks and two seats, provides privacy as well as comfort for off-duty flight attendants. By using this compartment, ten more profit seats are available on the main deck of the aircraft. Boeing

The Flight Deck

Significantly, flight deck changes transformed a three-crew-member, analogue cockpit with electro-mechanical instruments – all familiar 747 characteristics – to a full digital, two-crew flight deck with cathode ray tube (CRT) displays, the flight engineer's systems being located in the roof between the two pilots. (The workload is designed to be half to one-third that of the standard 747.) Simplified and automated systems have reduced the number of flight-deck lights, gauges and switches from 971 to 365 on the -400, twenty-two fewer than the 757/767, and 100 less than the 737.

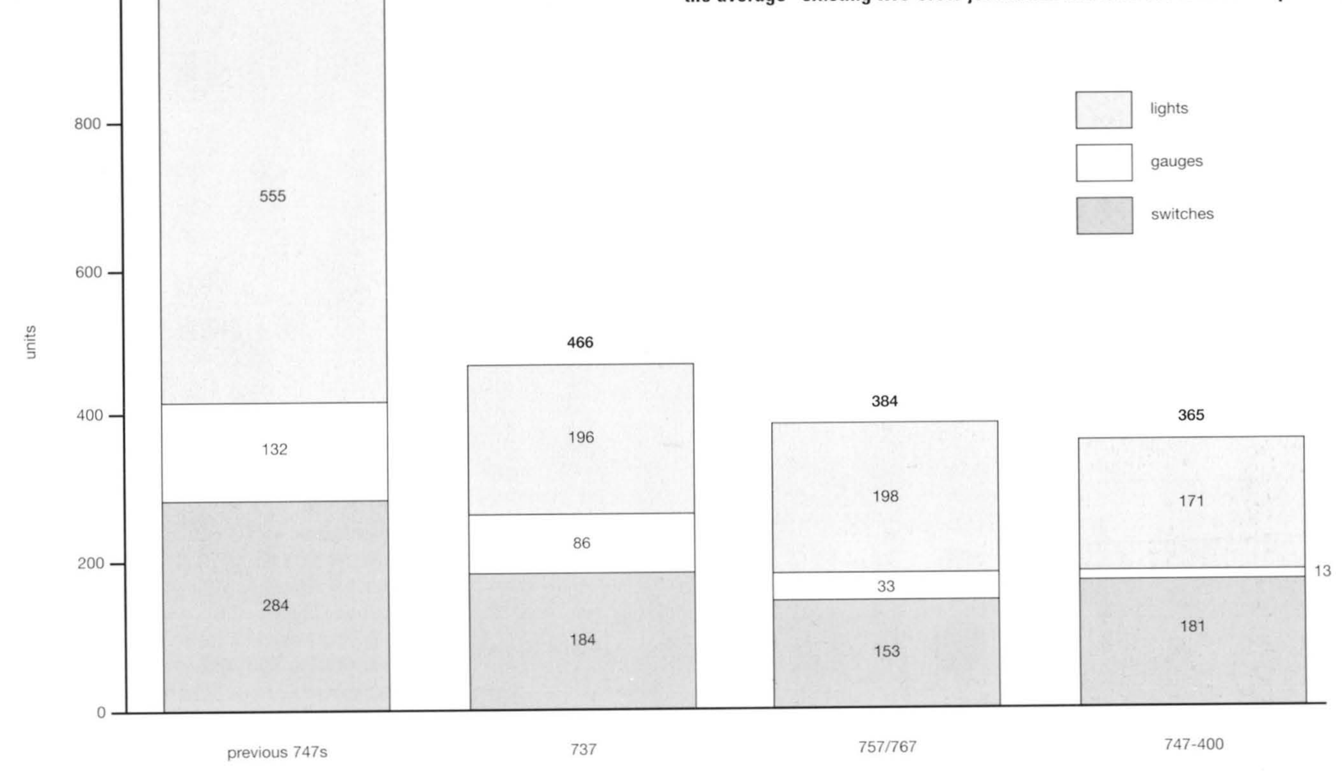
Streamlined processes and automation further reduce crew workload. There are 68 per cent fewer checklist items for normal procedures (for example, the -400 checklist has thirty-four line items compared to 107 for the earlier aircraft), and 75 per cent fewer steps are required to deal with non-normal procedures – a rapid cabin depressurization and emergency descent requires just three actions, as compared to twenty on older versions. In the event of an engine fire, the -400 crew need to check off four line items, down from fifteen on the -200 or -300. Whereas a cargo fire needed sixteen actions on the older types, only two are needed on the -400.

Because of the great differences in the two-crew cockpit and the revised instrumentation, pilots qualified on earlier variants of the 747 must be trained and qualified specifically for the -400.

747-400 Digital Cockpit

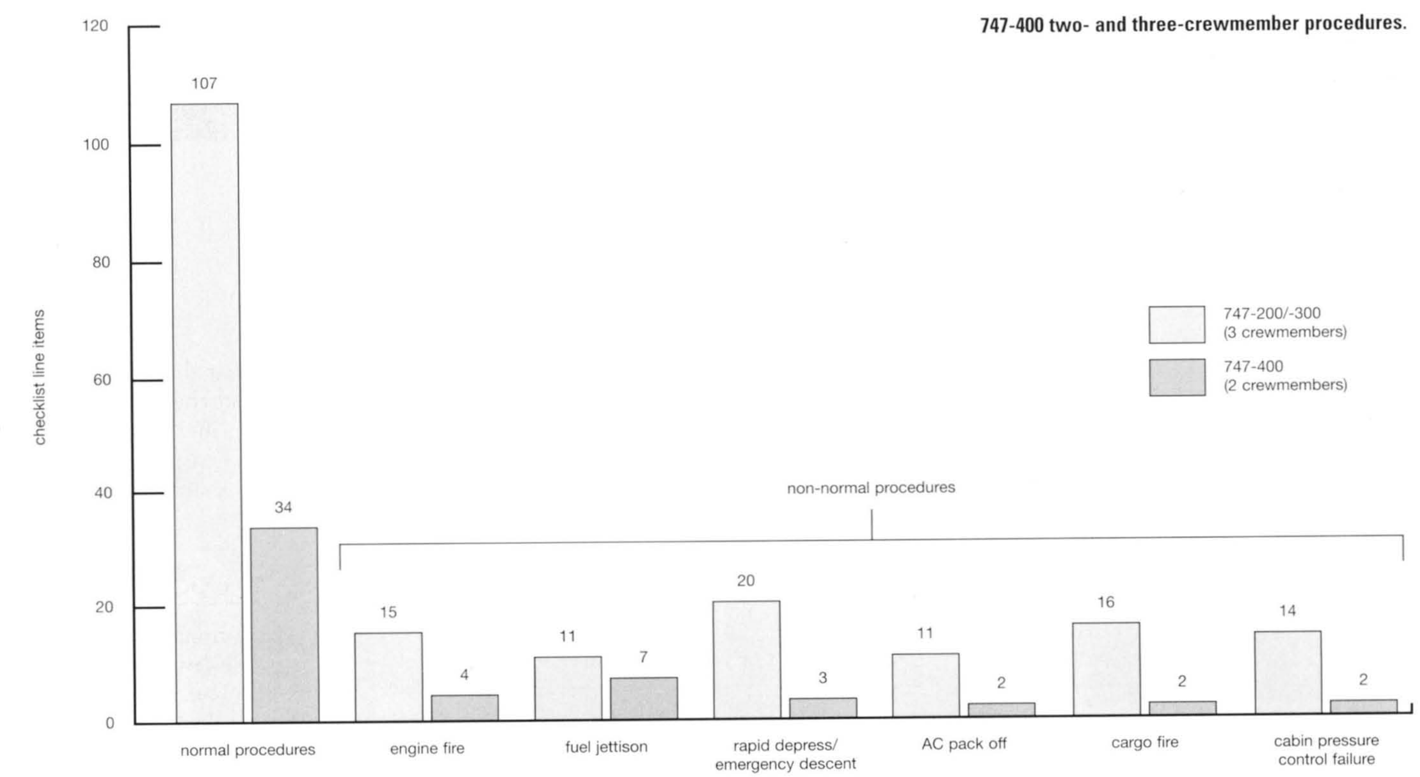
The major flight information is displayed across six side-by-side (unlike in the 757 and 767, where they are one above the other), interchangeable Collins 8 × 8in (200 × 200mm) integrated display system (IDS) screens, or CRTs, which allow more information to be displayed. The

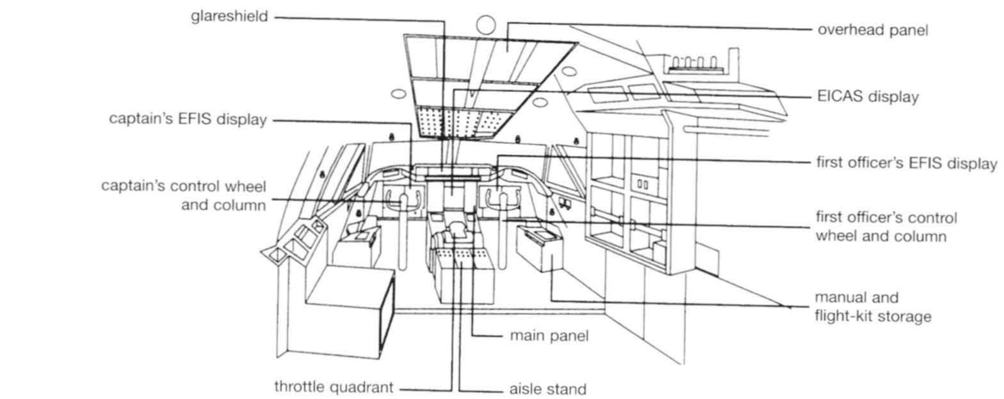
747-400 flight deck simplicity. The 747-400 has fewer lights, gauges, and switches than the average* existing two-crew jet airliner and over 600 fewer than previous 747s.



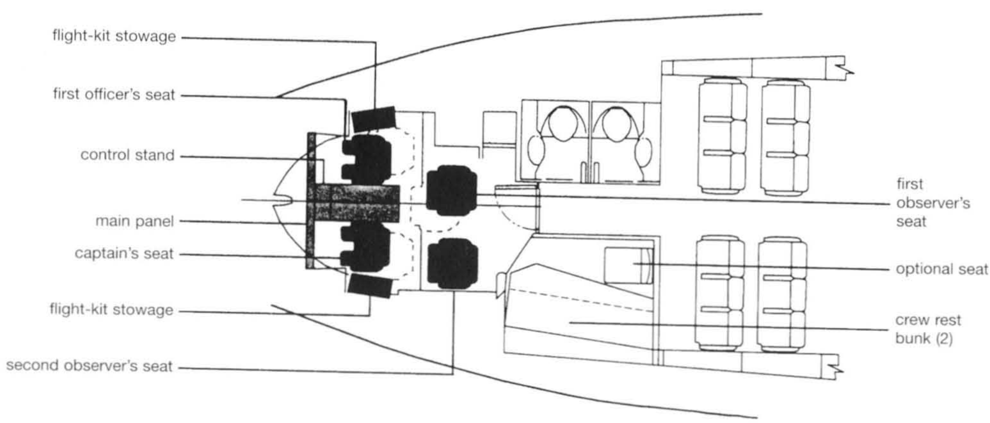
Note: Navigation and communication panels are not included
** approximately 450 is average for existing two-crew jet transports.*

747-400 two- and three-crewmember procedures.

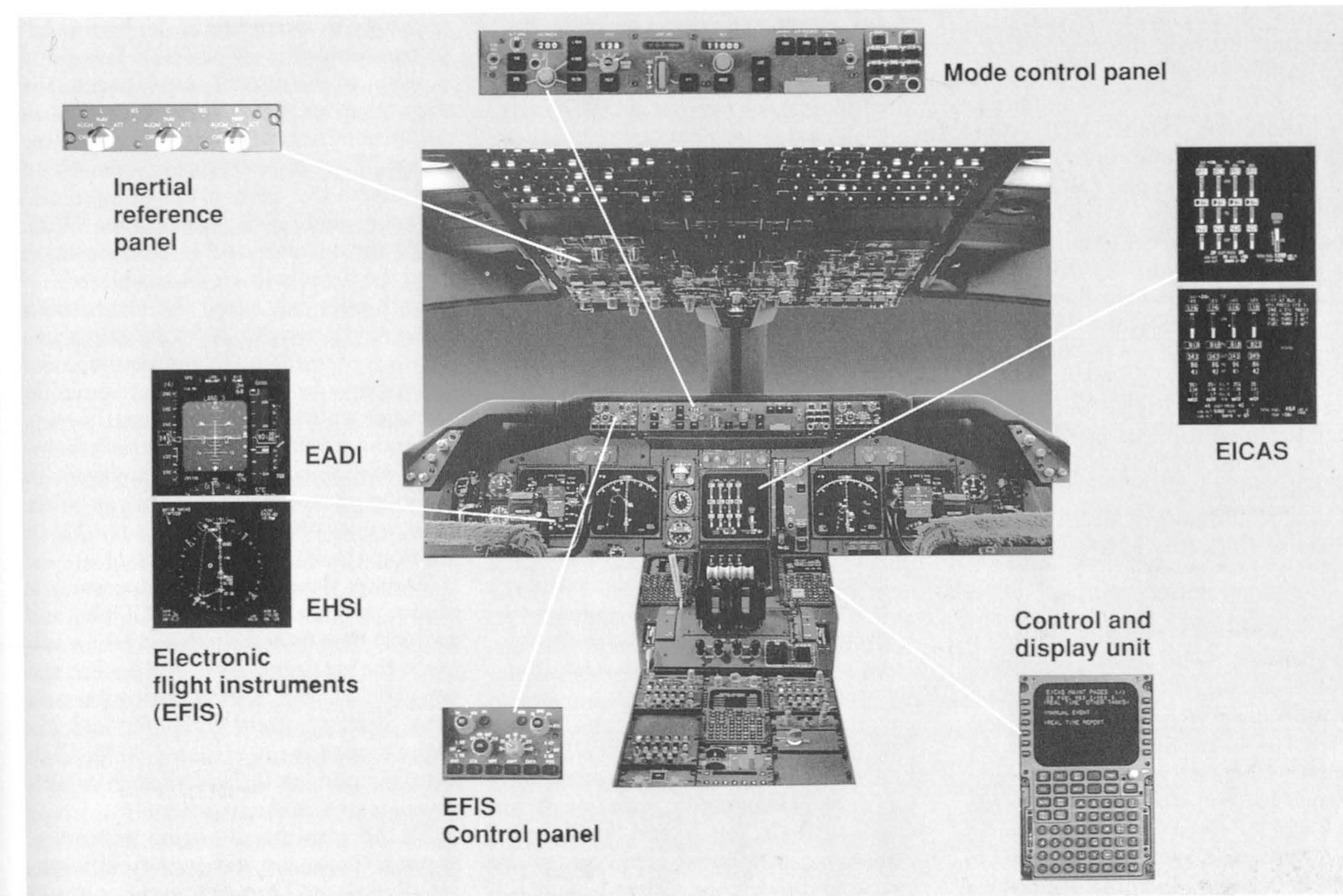




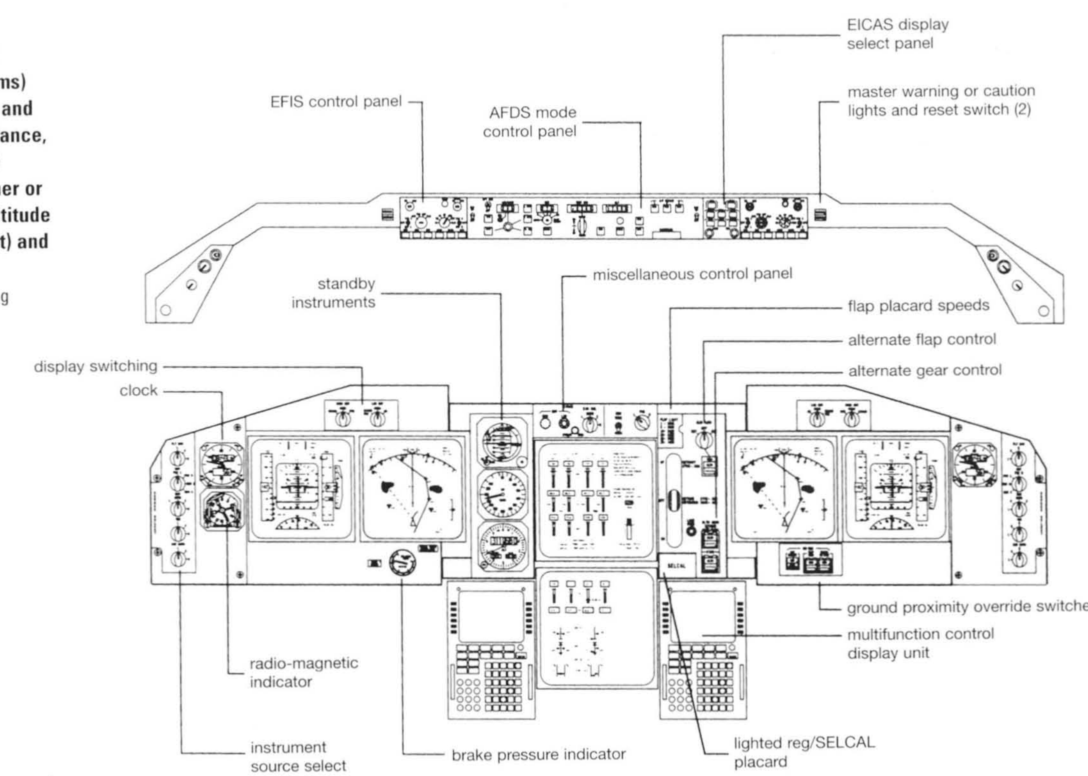
Flight-deck arrangement.



(Below) The 'glass' or 'digital' flight deck of the 747-400. Significantly, flight-deck changes transformed a three-crew-member, analogue cockpit with electro-mechanical instruments to a full digital, two-crew flight deck with cathode ray tube (CRT) displays; the flight engineer's systems were located in the roof between the two pilots. Simplified and automated systems have reduced the number of flight-deck lights, gauges and switches from 971 to 365 on the -400, nineteen fewer than the 757/767 and 101 fewer than the 737. Boeing



(Above) The latest 'glass' or digital avionics, including improved EFIS (electronic flight instrument systems) displays with their fault warnings and corrective actions, collision avoidance, data-link, wind-sheer warning, 4D navigation (a calculation of whether or not the -400 can reach a certain altitude by a certain navigational waypoint) and digital electronic engine control (known as 'power by wire'). Boeing



Main panel.

primary flight display (PFD), or the EADI (electronic attitude director indicator), displays aircraft attitude, altitude, horizon, airspeed, vertical speed and heading. The navigation display (ND) or EHSI (electronic horizontal situation indicator), which replaces the earlier 'moving map' and which shows track, heading, wind and distance, are duplicated. (On the captain's side the left-hand display unit is the PFD; his right-hand screen is the navigation display. The display screens are reversed for the first officer.) Two engine indication and crew alerting system (EICAS) display units, located centrally, monitor the performance of various systems, and alerts the crew of any abnormal conditions.

David Hollingsworth, head of customer support at Rolls-Royce, writing in 1994, said:

> The monitoring of engines in flight has made great strides in the last decade. Early attempts were abortive because of the poor reliability of the sensors and measuring equipment used. There were also problems in analysing the vast amount of data collected. For many years, the warning devices in aircraft were often less reliable than the equipment they were monitoring. For example, pilots were accustomed to false fire warnings. Today that situation has changed. Although sensors are subject to vibration and wide variations in temperature and pressure, modern transducers are much more reliable and accurate than those of the past. Digital systems have led to an increase in the number of parameters being measured, providing the opportunity for condition monitoring in greater depth.
>
> Modern fuel systems with full-authority digital engine control (FADEC) make it easier to monitor engines via the digital databus used on the latest airliners. Electronic equipment is designed with built-in test equipment (BITE) and a carefully chosen level of redundancy. The BITE enables it to identify internal electronic failures or obviously false sensor signals (for example, a shaft apparently running at 150 per cent of its maximum speed), and to give an indication to maintenance personnel. The redundancy allows the equipment to continue to function to a satisfactory level, even with some failures in the system. The failures can then be fixed at a time convenient to the operator.
>
> With condition-monitoring today, data is gathered on a sampling basis when the equipment is in use, and recorded for subsequent analysis and interpretation. The processing of data converts measurements into useful information. Measurements are made only to provide 'snapshots' of performance and engine behaviour at selected stages of a flight – after lift-off, and during climb and cruise. These techniques avoid the costly collection of masses of unnecessary information, and thousands of man hours needed for its subsequent analysis.
>
> Sampled data can be recorded in flight on cartridges or disks which are transferred into ground systems when the aircraft lands. A further enhancement to this system enables information to be transmitted in flight to ground stations and analysed, so that any maintenance action necessary can be taken immediately after the aircraft lands. This is particularly valuable in long-haul operations, when an aircraft may be away from base for several days.
>
> Ground-based computer systems can now analyse the data gathered in flight, and report 'by exception' – signalling only when unusual events are occurring, or trends in engine behaviour are moving close to limits, indicating that maintenance action is necessary.

The primary flight display (PFD), or the EADI (electronic attitude director indicator) displays information regarding the aircraft's attitude, pitch and bank, speed deviation, instrument landing system course, and glidescope. Other data, such as autopilot and autothrottle modes, groundspeed and radio altitude, are also displayed. Airspeed is displayed in a vertical tape on the left, with barometric pressure, attitude and vertical speed on the right. Aircraft heading is shown on a box on a compass arc at the foot of the screen. The EADI, along with the EHSI, presents information regarding complete aircraft attitude and position to the pilots throughout all phases of the flight. The presentation format capitalizes on the best features of the traditional electromechanical instrumentation, and incorporates new features that are only possible on a programmable CRT display.

The navigation display, or EHSI, has four modes with approach, VOR, map (with a maximum range of 736 miles/1,184km) and flight plan, with either the full compass rose or an enlarged quadrant. (The aircraft symbol can be located in the centre to permit the pilot to view all around in busy terminal areas where ATC instructions may involve tight manoeuvres.) Essentially, the ND integrates compass, track, weather and map references into a single display, with all the elements presented in a common scale. In a multicolour format, it depicts the horizontal position of the aircraft in relation to the flight plan, and displays a map that shows navigation features of the surrounding region. This improves crew orientation and allows the pilot to make rapid and accurate flight-path corrections. Wind speed and direction and vertical deviation from the flight path are also displayed.

Each pilot may adjust the composition of his navigation display by choosing from a variety of features. Colour weather radar returns may be selected and presented at the same scale and orientation as the map. Altitude and time of arrival for each flight-plan waypoint can also be displayed. In addition to map mode, a pilot can select plan mode, VOR mode, ILS mode, or (optional) full compass rose mode.

Primary data for aircraft operation is shown on the CRTs and CDUs, and includes data from the following three systems: the electronic flight instrument system (EFIS), the engine indication and crew alerting system (EICAS), and the flight management system (FMS). EFIS contains primary flight data such as altitude, air data, and navigation.

EICAS presents all engine indication, thrust management and caution and warning displays, and can call up the status or schematics of various systems at any time on one of the CRTs. The primary role of the EICAS computers is to monitor the hundreds of signals sent from the engine and subsystem sensors during a flight. Information the crew requires in flight, either full time or on command, is displayed at the flight deck in a multicolour format that can be read quickly and easily. Primary engine data such as fan speed, thrust, and jet temperatures and pressures are displayed in the upper screen in either round-dial or tape format. Also displayed is major 'aircraft-status' information about landing gear and flap positions, doors, tyres and fuel states. The lower screen displays more engine data such as compressor speeds, oil pressures and temperatures, as well as 'synoptics' of the hydraulic, electrical and fuel systems. Circuit-breakers and other functions previously located on the flight engineer's panel are located overhead.

On the ground after the flight, the EICAS computer performs an equally vital role in providing maintenance crews with an automatic record of any system malfunction during the flight. In addition,

crew can command EICAS to record data for trend analysis, including details pertaining to flight profile, temperature, and other conditions that affect the system's performance.

The Honeywell (Sperry) flight management computer system (FMCS) stores flight plans to reduce crew workload and navigation errors. It takes a maximum of just three seconds to complete a calculation which took up to twenty seconds on the earlier 747. The system calculates the optimum altitude, speed and routing for a flight, given the relevant inputs from the pilots. Importantly, the FMCS has the capability to carry out '4D' navigation.

In addition, information shown on the three multifunction control display units (MCDU) can be selected by the pilots as required. The MCDUs can display data regarding standby navigation, automatic navigation radio tuning, and dual-integrated thrust management, and can access the central maintenance system and a host of other functions. A multipurpose printer is included to provide inflight printouts of datalink information and suchlike. Should a primary flight display fail, the information can be immediately switched to the navigation display panel, with the other pair still operating. Automatic or manual display switching is used as back-up in the event of an individual CRT failure. Conventional electro-mechanical airspeed, altitude, vertical speed and compass instruments are fitted, so if a total failure of all the flight and navigation displays occurs – an unlikely event – the pilots can still operate safely.

Other new flight-deck features include a full-time autothrottle, streamlined throttle quadrant and dual-thrust management system in the FMC. There is also automatic start and shutdown of the APU, and integrated radio communication panels. The Collins autopilot flight-director system (AFDS) hardware is basically identical to that fitted to the 757/767, but the FCS-700A has updated software. An important new facility on this full digital triplex system is 'altitude intervention', which can handle an unexpected change of height caused by ATC instruction without the crew having to recalculate the flight plan. The AFDS also controls the auto-land capability of the -400, and is cleared to bring the aircraft in for automatic landings with a decision height of 0ft and a forward view along the runway of under 655ft (200m).

The Collins central maintenance computer (CMC), located on the console between the pilots, interfaces with the -400s digital data bus and constantly monitors seventy individual systems centrally, giving faults in plain English on the CRT. Using this system, both flight and maintenance crews can obtain an update of the aircraft's mechanical condition (previously the information was only available to maintenance workers on the ground), to locate and correct faults.

The Upper Deck

Travellers always want as much personal space as possible, but the real question is whether the value they place on extra space will generate additional revenue. Comfort is rated four times more important on long-range than on short-range flights, and only first-class and business-class passengers are consistently willing to pay a premium for additional space and amenities. The 747-400 offers more options for passenger comfort. Seating alternatives for high-yield travellers on the upper deck can include twenty-six sleeper seats, thirty-eight first-class seats, or forty-two to fifty-two business-class passenger seats. In addition, up to ninety-one passengers can be seated on the upper deck in an all-economy, 34in (86cm) seat-pitch arrangement.

Most -400 operators have a seating capacity for 380–450 passengers, depending on the ratio of first-class business- or club-class and economy-class seats. KLM 747-400s seat a total of 387 passengers in an 18/105/264 layout, while Air New Zealand seats 396 passengers in a 16/56/324 layout, and United Airlines' -400s accommodate 436 passengers in an 18/68/350 configuration. In British airways service, the 747-400 carries up to 426 passengers, but the standard configuration is for 401 passengers in a three-class layout (fourteen First, fifty-five Club World, 332 World Traveller). Late in 1995, British Airways' innovative new First service offered passengers, for the first time, their own individual cabins which they can use as a private office or mini-meeting room, also an entertainments centre, a dining room for two, or a bedroom, complete with a flat, 6ft 6in (2m) full-length 'flying bed' at the touch of a button. This provides unrivalled levels of privacy and comfort.

The modern upper deck features a large galley with room for twenty food and beverage carts, and two or three toilets; it also has nineteen more windows. Two new full-wing doors replace existing 747-200 upper deck exits. An aft straight stair replaces the original 747 forward circular stair. Upper deck passengers also have side-wall stowage that can serve as a table or additional work surface.

The Main Deck

The 747-400 interior has ceiling and sidewall panels recontoured with new, lighter materials that are easier to maintain, and the volume of overhead stowage in both side and centre bins has increased dramatically. New materials on partitions, doors, closets, galleys, toilet walls, and other interior surfaces meet Boeing goals for fireworthiness. The new, flexible interior allows operators to install sidewall galleys and toilets without changing the ceiling and its support structures. The modular outboard overhead stowage bins can be removed to make way for a new galley or toilet. As passenger seats are relocated, passenger and entertainment services can be reprogrammed using the Advanced Cabin Entertainment and Service System (ACESS).

The Lower Hold

The lower hold in every 747 has a mechanized loading system for cargo and baggage, and 6,025cu ft (170cu m) of containerized cargo volume. On-board powerdrive systems and optional pallet-handling hardware in the lower hold can work with a mix of standard containers and commercial and military pallets. One attendant at the compartment doorway transfers cargo modules to their positions over a surface of ball transfer units and rollers. An additional 835cu ft (23.6cu m) of bulk cargo can be loaded into the 20ft- (6m-) long bulk cargo compartment of the 747-400, where it is attached to floor fittings or held in position by floor-to-ceiling nets.

Testing Times Again

On 22 October 1985, lead customer Northwest Airlines ordered the first 747-400. The first 747-400, C/n.23719/Line number 696, a -451 (N661US) for Northwest, was rolled out at Everett on 26 January 1988, the same day as the new 737-400 was rolled out of the

Boeing-Renton plant – the first double roll-out in the company's long and distinguished history. The first of the -400s took off from Paine Field near Everett on 29 April to begin the intensive flight-test programme, which would certify three different engines: the P&W PW4000, the General Electric CF6-80C2, and the Rolls-Royce RB211-524G. In all, four -400s were used for the basic -400 certification. Aircraft numbers one and four were used for certification with the P&W engines, number two for the GE engines, and number three for the Rolls-Royce powerplants. Number 4 was used for aircraft interiors installation requirements, and also demonstrated reduced workloads in two-crew operations. It was envisaged that the total programme would require approximately 2,400 hours of testing, of which about half would be in the air.

On 26 May 1988 the 747-400 completed the longest engineering flight in Boeing commercial aircraft history. This marathon flight lasted more than fourteen hours as cruise performance was evaluated. Forty-nine cruise data points were taken at eight different altitudes and at a series of Mach numbers, making this one of the most productive tests ever. In addition to cruise performance, other tests included a lapse-rate take-off (engine thrust characteristics measured during acceleration), take-off trim evaluation, and an auxiliary power unit (APU) performance evaluation.

On 27 June, at Moses Lake, Washington, 747-451 – temporarily registered N401PW to publicize the PW4000 engine – set a new official weight record by reaching an altitude of 7,000ft (2,000m) at a gross weight of 892,450lb (404,815kg). (The aircraft was accepted by Northwest Airlines in 1989 as N661US.) In late August 1988, the first 747-400 flew to Roswell, New Mexico, to test the lighter, tougher carbon brakes in a series of refused take-offs (RTOs), which contribute to a picture of 747-400 braking characteristics for the FAA. A test is completed by advancing the -400's throttles to full power, releasing the brakes, and accelerating to a predetermined ground speed just before a simulated engine failure. The pilots then reduce the 'good' engine power to idle, apply maximum wheel-braking and extend the wing spoilers. Thrust-reversers are not used during the tests. An 870,000lb (394,630kg) gross weight RTO was successfully performed in the first week in September 1988 at Edwards AFB in the high desert of Southern California.

On 22 October 1985, lead customer Northwest Airlines ordered the first 747-400 (C/n. 23719/line number 696), a -451 (N661US), seen here on the Boeing production line at Everett. A significant weight-saving of some 4,200lb (1,900kg) has been achieved through the use of new, lighter, high-strength aluminium-lithium alloys with improved fatigue life incorporated in the upper and lower skins of the wing torsion box, stringers and lower-spar chords. All areas of the structure which were previously prone to fatigue cracks were strengthened, the large front end having thicker frames, skins and doublers to obviate expensive repair procedures. Metal flooring previously used in the passenger cabin was replaced by light, tough graphite floor panels. Corrosion protection was further improved by white epoxy paint in the under-floor areas, especially in the areas below and around the toilets and galleys. Boeing

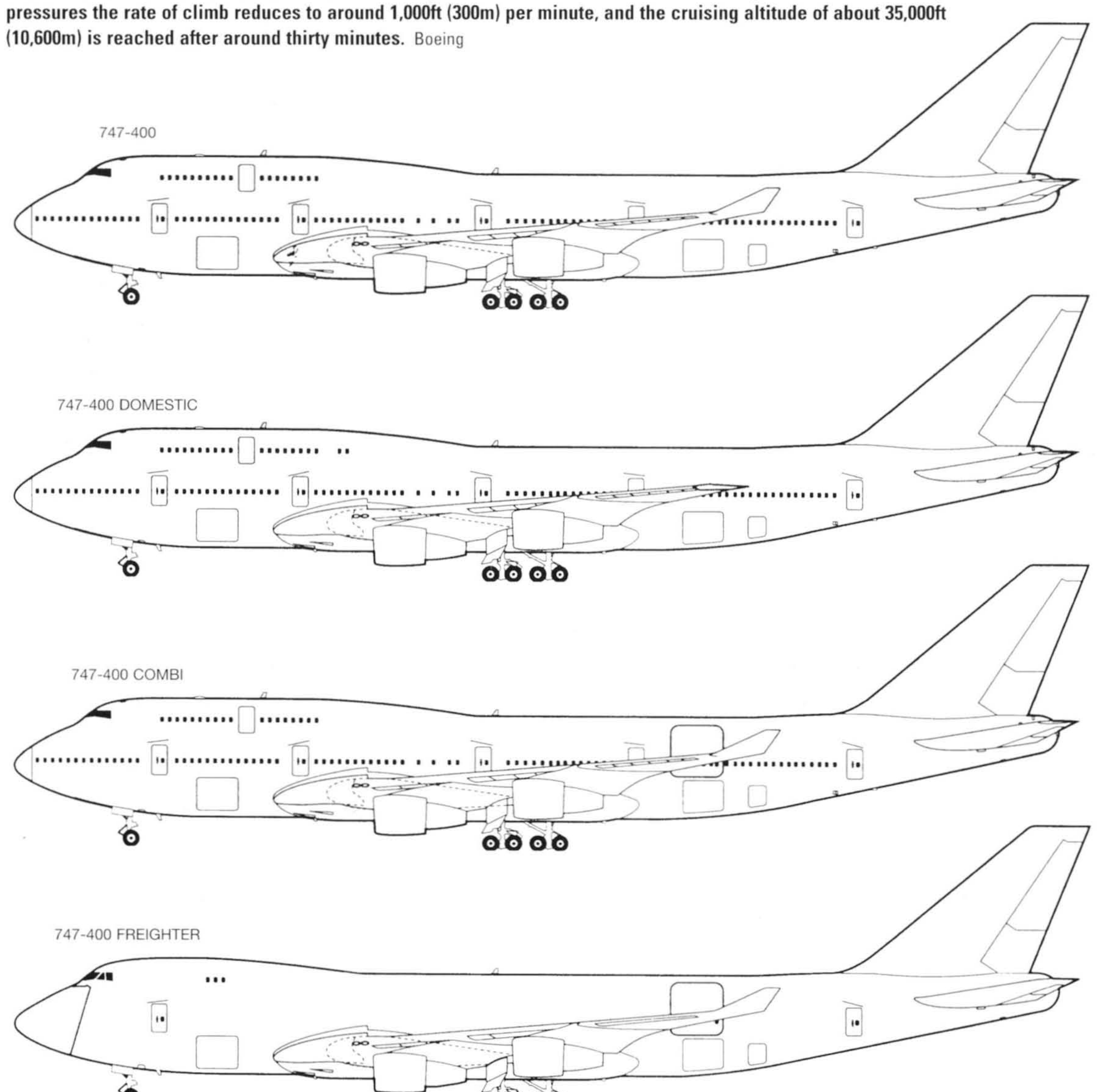
First Deliveries

In 1986, five more airlines –British Airways, KLM, Lufthansa, Cathay Pacific and Singapore Airlines – placed firm orders for forty-nine -400s. (In Singapore Airlines' service the -400s are known as 'Megatops', and this logo is painted on the forward fuselage – just as the 'Bigtops' logo is on the airline's -300s.) In 1987 a further fifty-eight aircraft were ordered by United Airlines and Air France. By June 1988, Boeing had received orders for 146 -400s from nineteen airlines. The first -400 to be

The first 747-400, C/n.23719/line number 696, a -451 (N661US) for Northwest, was rolled out at Everett on 26 January 1988. The outward-canted winglet immediately distinguishes the -400 from earlier models. Mounted at each wing-tip, these winglets, which are of graphite (carbon-fibre) composite front and rear sparred with a carbon-fibre and epoxy honeycomb sandwich skin, increase the aspect ratio of the wing, thereby reducing induced drag and increasing the range of the aircraft by a calculated 3 per cent. The winglets also aid the -400s take-off characteristics and permit higher cruising altitudes to be flown. To further improve take-off and landing performance, an additional leading-edge flap is fitted to the wing extension. Boeing

(Below) **N661US flew for the first time on 29 April 1988, and on 26 May completed the longest engineering flight in Boeing commercial aircraft history, lasting more than fourteen hours, as cruise performance was evaluated. On 27 June, at Moses Lake, Washington, 747-451, temporarily registered N401PW to publicize the PW4000 engine, set a new official weight record by reaching an altitude of 7,000ft (2,000m) at a gross weight of 892,450lb (404,815kg).** Boeing

N661US, seen here taking off on its delivery flight, was accepted by Northwest Airlines in 1989 as N661US. Fully loaded, a -400 weighs over 250 tons, yet after about fifty seconds from beginning to roll, at a speed of 170 knots, it will rise into the air at about a mile down the runway. Once the eighteen wheels are retracted, the -400 will climb at over 3,000ft (900m) per minute, and at 1,500ft (450m) the flaps are retracted and speed increased to 250 knots. With declining air pressures the rate of climb reduces to around 1,000ft (300m) per minute, and the cruising altitude of about 35,000ft (10,600m) is reached after around thirty minutes. Boeing



747-400 variants.

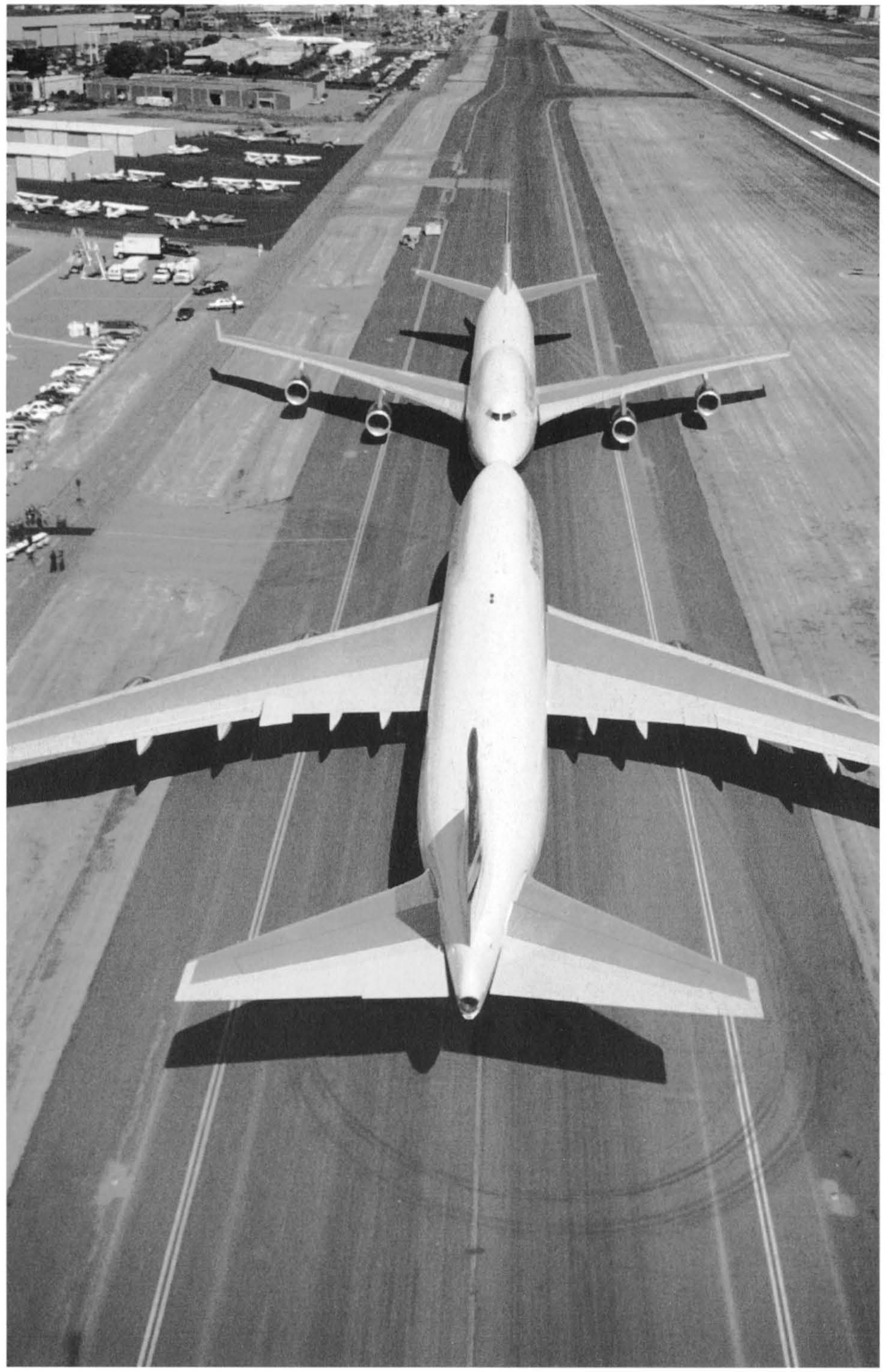
actually delivered to an airline was Cathay Pacific's VR-HOO (C/n.23814), which arrived at Hong Kong on 28 August 1988. The -400 was finally certificated on 10 January 1989, but because the FAA insisted on further software and other electronic alterations, N661US could not be delivered to Northwest until 26 January. The airline put N661US into service on 9 February on its Phoenix-Minneapolis route.

The 747-400 has a near 100 per cent safety record, two -400s being written off in crashes in 1993. The first, F-GITA of Air France, landed at Papeete on 12 September, and then for some reason veered off the runway and came to a halt on the beach where its nose became immersed in shallow water. Fortunately, none of the 272 passengers and crew suffered any lasting injuries.

The second incident involving a -400 occurred on 4 November 1993 when a China Airlines' 747-409 (B-165, which had just been recently delivered, on 8

The 747 marked its twentieth anniversary on 30 September 1988 when N7470, the first built, followed by the newest model, the -400 (N6038E/PH-BFC Calgary **for KLM-Asia Airlines, the 735th 747 built), flew in close formation over each of Boeing's major plants in the Puget Sound area, as well as downtown Seattle, Washington, seen here. On board the lead aircraft as passengers were Jack Waddell, Brien Wygle and Jess Wallick, the original N7470 flight crew. At the time, orders for the 747 stood at 877 (including 161 for the new -400 version, of which 703 had been delivered).** Boeing

June) ran off the runway at Kai Tak, Hong Kong after landing in heavy rain and strong winds caused by a nearby typhoon. The pilot quickly ran out of runway and tried to turn B-165 90 degrees onto the taxiway at the end of the runway, but without success, and the aircraft slid backwards into the waters of Victoria Harbour. Fortunately it refused to sink, thanks to the inbuilt buoyancy and strength of its construction, and all 296 passengers and crew escaped without any serious injuries. B-165 remained afloat but its tail, which protruded high into the air near the runway, was too much of an obstruction for other aircraft and it had to be blown off by explosive charges so that Kai Tak could be put back into use. B-165 was later recovered, but because of the corrosion caused by the salt water, it could not be put back into service again. It is now used as an instructional airframe at Xiamen.



On 29 July 1989 a ceremony at Seattle was held to mark the handover of British Airways' first two 747-436s, G-BNLA City of London **and G-BNLC** City of Cardiff/Dinas Caerdydd. Boeing

Model 747-400M Combi

The Combi version of the 747-400, introduced in 1985, features a large (134 × 120in/3.4m × 3m) cargo door on the main deck aft of the wing on the left side, plus equipment that allows passenger seats to be removed and cargo tracks to be installed, giving carriers the option of carrying containerized or palletized cargo in the main deck behind the passengers. The large, side cargo door means that cargo can be loaded in the aft section at the same time as passengers are boarded in the forward section; this allows for rapid turnaround and through-stop operations. A locked partition separates the passenger compartment from the cargo area, which is accessible only by the crew. Roller trays on the aft floor facilitate loading of 8ft- (2.4m-) wide containers, or pallets up to 20ft (6m) long. The Combi can handle large-volume shipments such as cars, small boats, heavy machinery, drilling equipment and even small aircraft or helicopters. Environmental control in the cargo area allows transportation of live animals, perishable foods and cut flowers/vegetables, while maintaining separate environmental control of the passenger cabin.

All-passenger or six- or seven-pallet configurations allow carriers to meet seasonal fluctuations in traffic. Typical mixed-passenger and six- or seven-pallet arrangements accommodate 266 passengers and more than 9,000cu ft (255cu m) of cargo. The 747-400 Combi provides 1,100 miles (1,770km) greater range, with 12,000lb (5,440kg) more payload than previous Combis. It carries more passengers than a widebody trijet, and handles about as much cargo as a 707. Cargo operations do not interfere with passenger service because main-deck cargo loading occurs in an area of the aircraft where there is normally no activity.

G-BNLA City of London **and G-BNLC** City of Cardiff/Dinas Caerdydd, **the first two 747-436s for British Airways, on the ramp at Seattle. Behind BNLC is 747-412 9V-SMC of Singapore Airlines, and in turn, -400s of KLM (the first European Carrier to operate the -400) and Korean Air. On the runway is a Cathay Pacific -400.** FT via British Airways

KLM was the initial customer, ordering four with CF6-80C2 engines in April 1986, for delivery starting in February 1989. Three other airlines have also ordered 747-400Ms. Altogether, twenty-one airlines had ordered a total of 161 Model 747-400s by the end of September 1988.

747-446D (SR)

In October 1989 Boeing announced that it planned to build the 747-400 high-capacity Domestic, the latest in the long line of short-range (SR) 747s operated by Japan Air Lines and All Nippon Air Lines. Once again, major structural strengthening was used in the construction to take account of the increased take-off and landing cycles. Externally, the -400D can differ from the standard -400 in not having the 6ft (2m) winglets fitted, because these tip extensions, being designed to reduce drag on long haul flights, are unnecessary on short, intra-flights in Japan (although carriers have the option of having them fitted). In fact the fuel saving is so negligible that it is more cost-effective to dispense with the winglets and their associated increase in weight. There is no tail-tank fitted, and this has helped reduce the aircraft's gross weigh to around 600,000lb (272,160kg). The -400D can carry 568 passengers in all-economy seating, the largest number of passengers on any commercial aircraft in existence. The first 747-446D, C/n.25213, line number 844, flew on 15 March 1991 and went into commercial service with JAL (JA8083) on 10 October 1991. By the end of 1998 JAL had received eight -446Ds, and ANA had taken delivery of ten -481D versions, of which three were later converted to standard -446 configuration.

747-4H6M Combi 9M-MHL of Malaysia Airlines which first entered service in November 1989, taxiing at Frankfurt on 23 February 1990. Graham Dinsdale

On 10 September 1993 Boeing celebrated the rollout of the 1,000th 747, a 747-412 (9V-SMU) for Singapore International Airlines. 9V-SMU flew on 29 September and was delivered to SIA in October. Boeing

In Singapore Airlines' service the -400 is known as the 'Megatop' and this logo adorns the top deck forward of the aircraft. Tim Moore via Barry Reeve

***(Below)* 747-406M PH-BFO** Orlando **of KLM on finals at Kai Tak in 1993. By November 1996 KLM were operating seventeen GE CF6-80C2-powered -406s, twelve of them Combi aircraft, and another three Combis were on order for delivery in 1997–98.** KLM

***(Below)* 747-400s being prepared for delivery in April 1994. Since 1990 Boeing had spent more than $1 billion on the 777 Working Together Celebration project, which included expanding the size of the Everett final assembly building (lower centre) from 63.3 acres (25.6 hectares) to 98.36 acres (39.84 hectares). In addition, two office buildings (top) had been built to house engineering and administrative personnel, and a third paint hangar (bottom, far right) had been added to paint 777s, as well as 747s and 767s.** Boeing

Air India 747-437 VT-ESN. The distinctive paintwork highlighting the cabin windows, which was first used on the company's -200 series, led to the aircraft being called 'Palaces in the sky'. Late in 1989 Air India brought in a new livery which omitted the 'Palace windows' and caused such a furore that they were reinstated on the -437 series. Barry Reeve

747-408 G-VTOP Virginia Plain **of Virgin Atlantic getting airborne.** Boeing

747-4J6M B-2466 of Air China taxiing at Kai Tak, Hong Kong, 13 February 1996. Graham Dinsdale

East meets west at Kai Tak. Air China 747-4J6 B-2443 (left) and China Airlines' 747-412 3B-SMC (9V-SMC) (right). Graham Dinsdale

Three members of the Boeing family of commercial aircraft at Seattle in September 1996, prior to delivery to British Airways. In the foreground is a 747-400, the thirty-fourth -400 built. In the centre is a 777-200 and behind, a 767-300ER long-range twin-jet, the most widely used aircraft on North Atlantic routes. Boeing

Principal Characteristics

	747-400 Domestic	747-400 Combi		747-400 Freighter	
		All Passengers	*7 Main Deck Pallets*	*Basic*	*Maximum*
Weights lb (kg)					
Maximum takeoff gross weight	600,000 (272,160)***	870,000 (394,630)*		800,000 (362,880)	870,000 (394,630)
Maximum landing weight	574,000 (260,370)	630,000 (285,770)		652,000 (295,750)	666,000 (302,100)
Maximum zero fuel weight	535,000 (242,680)	565,000 (256,280)		610,000 (276,700)	635,000 (288,040)
Typical operating empty weights:					
General Electric engines	386,600 (175,360)	409,300 (185,660)	403,900 (183,210)	366,400 (166,200)	366,400 (166,200)
Pratt & Whitney engines	386,600 (175,360)	409,200 (185,600)	403,800 (183,160)	366,800 (166,380)	366,800 (166,380)
Rolls-Royce engines	–	412,000 (186,880)	406,600 (184,450)	369,900 (167,800)	369,900 (167,800)
Fuel capacity US gal (L)					
General Electric engines	53,765 (203,500)	57,065 (215,990)		53,765 (203,500)	57,065 (215,990)
Pratt & Whitney engines	53,985 (204,330)	57,285 (216,820)		53,985 (204,330)	57,285 (216,820)
Rolls-Royce engines	–	57,285 (216,820)		53,985 (204,330)	57,285 (216,820)
Dimensions ft-in (m)					
Length	231-10 (70.66)	231-10 (70.66)		231-10 (70.66)	
Wingspan	195-8 (59.64)	211-5 (64.44)		211-5 (64.44)	
Height	63-8 (19.41)	63.8 (19.41)		63.8 (19.41)	
Engines					
Type	CF6-80C2B7F	CF6-80C2B7F		CF-80C2B7F	
Thrust (lb)	61,500	61,500		61,500	
Type	PW4062	PW4062		PW4062	
Thrust (lb)	62,000	62,000		62,000	
Type	–	RB211-524H		RB211-524H	
Thrust (lb)	–	60,600		60,600	
*Design range** nmi (km)*					
General Electric engines	1,720 (3,185)	7,055 (13,070)	6,620 (12,250)	3,150 (5,830)	4,335 (8,030)
Pratt & Whitney engines	1,690 (3,130)	6,985 (12,940)	6,550 (12,130)	3,105 (5,750)	4,275 (7,920)
Rolls-Royce engines	–	6,920 (12,820)	6,485 (12,010)	3,120 (5,780)	4,295 (7,950)

* *MTOW of 875,000lb (396,900kg) available with loading restrictions; **Based on 210lb (95kg) per passenger and baggage; *** Maximum design takeoff weight is 833,000lb (377,840kg)*

CHAPTER TEN

'Cathay 403, Will You Accept a Visual?'

Captain Mike Rigg

'Cathay 403 leaving flight level 350, descending 140.'
'Roger Cathay 403 turn left 260 for separation, and call passing flight level 290.'
'403, heading 260, will call passing level 290, where's the traffic?'
'403, your traffic is company L1011, passing level 280 for 290, in your 10 o-clock 20 miles.'
'Roger, looking.'
'What a beautiful day Jim, Christ, you can see for ever!'
'Yeah, what a shame to be up here, a man of your talent could be shining the ass of your suit with the tossers on the tenth floor, you don't have to suffer like this Mike!'
'Thanks Jim.'

The big aeroplane, light today by 400 standards at only 238 tonnes (238,000 kilos) with 13 tonnes of that being the remaining fuel, was descending rapidly at 300 knots and around 3,000ft per minute. Inside the flight deck it was 22 degrees Celsius, very dry, only about 18 per cent humidity and at this speed, the wind noise was moderate. Outside, of course it was very different. A monstrous din in the maelstrom of a 300 knot hurricane with the temperature in the minus 30s Celsius, a wild and turbulent world where no human could survive unprotected. Skin frozen, gut and lungs distended, joints torn asunder and brain starved of oxygen, death would, mercifully, be instantaneous. The long fall to earth would be of no consequence!

Through all this on she went with hardly a burble, smooth as silk in the stable airmass of a North East monsoon, passengers, even at this late stage, finishing their last drinks, sitting in comfort, many in shirt sleeves. All blissfully unaware of the chaos that prevailed a few millimetres from them on the other side of that amazingly thin skin of aluminium.

'Cathay 403, we have the traffic in sight and we're passing level 290.'
'Roger Cathay 403, you are clear of traffic. You are now cleared direct to the Charlie Hotel, maintain flight level 140 and call approach on 119.1.'
'403, direct to Charlie Hotel, 140 and call approach. It's a great day up here!' Jim's 'States' Canadian cheerfully breaking RT discipline; but what the hell, it was a great day up there, and it was about to get better.

Cathay 403 now left the Hong Kong radar frequency efficiently worked by the young 'local' with his clipped, precise and disciplined procedures and only a hint of Chinese accent brushing across his perfect English. They were now being handled by an 'import', an old hand who had arrived from the UK via the Middle East. Procedures maybe not quite so by the book but a man of vast experience. Instant team building, working together, a bond. I don't know why; I think it is in the voice. Exuding confidence, you know he is working for you.

It is important for the crew of an airliner to build up a mental three dimensional picture of their position, not only relative to the ground but also relative to other aircraft in the pattern. No matter how good the system or the people operating it, mistakes are made. The arbiters over disaster and safety are the crew, the last link in the safety chain. If all else fails their diligence, professionalism, call it what you will, could save the day. A vital aid enabling them to build this canvas is the controller. On a less dramatic point, by working together they help each other to make a smooth and expedient approach, thereby saving fuel, keeping the accountants happy, satisfying the passengers by avoiding unnecessary delays and the satisfaction of having done a good job permeates the mood. Good material for bullshitting in the bar later, too!

So as the 747 continued its descent the crew kept their eyes peeled, and even more importantly in the modern environment, they listened intently to the transmissions between ATC and other aircraft. They knew where everybody was. They knew where the dangers lay.

'Good afternoon Cathay 403, you are number 4 in sequence, number 1 is just about to touch down, would you like a visual step-down?'

'Is a pigs' arse pork; thoughts, not spoken! Number 1 will be clearing the runway, number 2 must be short finals, number 3 has just left Cheung Chau, we'll cut inside him – 'Tell him yes, Jim and ask him if we are clear up the Lamma Channel.' 'Affirm, you are clear up the Channel and you are 2 in sequence with number 1 on short finals, you are now ahead of the JAL who has just left the CH. Maintain 8,000ft, QNH 1010 until passing Tathong.'

That mental picture!

The visual step-down approach onto Runway 13 at Kai Tak airport, the old Hong Kong international, was one of the last real aviation experiences of the civil aviation world. No autopilots, no flight directors, throw away the INS and other navigation aids, even the ATC was minimal. It required good handling skills and mark 1 eyeball judgement, something a lot of modern aviators never get to practice. To many, this approach was something to be very wary of, but not to the Cathay pilots, they relished it! It was party time.

The flight path for this approach, if you were lucky, took you over Tathong Point round to the south of Hong Kong Island, passing between Lamma Island and the spectacular and beautiful Repulse Bay, where the Imperial Japanese Army earned themselves such infamy during World War Two, and then on to Green Island situated in the Western Harbour. From there you headed for Stonecutters Island (no longer an island I'm afraid, but now joined to the Kowloon Peninsula in that relentless march of progress). From Stonecutters you looked for the Kowloon Magistracy and thence for the famous 'checkerboard',

BA 747-436 making its turn at Checkerboard Hill on the approach to Kai Tak in February 1994. The IGS signals would be rejected by pilots at about 700ft (215m) and the aircraft flown towards the large red-and-white chequerboard at the foot of Lion Rock before commencing a sharp 40 degree turn onto Runway 13 at about 500ft (150m). Graham Dinsdale

(Below) **Lufthansa 747-430 D-ABVT on finals at Kai Tak.** Tim Moore via Barry Reeve

'CATHAY 403, WILL YOU ACCEPT A VISUAL?'

often peering desperately through the industrial pollution that had reduced the visibility to a bare minimum. From the checkerboard you made an almost right-angle turn to line up with the runway.

Round you went, a couple of hundred feet clear of apartment blocks and Mrs Wong's 'smalls' hanging out to dry, with Lion Rock looming ominously over your left wing and often a nasty little South Wester chucking you about and trying like a Chinese dragon to blow you through the centre line. Yes, 747s are affected by the wind, not even they can defy the laws of nature.

747-409 B-18202 of China Airlines on finals for Kai Tak, Hong Kong, 1 May 1998. Graham Dinsdale

On a seemingly benign and lovely day, windshear at this juncture could catch the unwary, and lead to the very least, an embarrassment and much mirth from one's fellow aviators, and in the worst case – it does not bear thinking about.

'Hell, it must be six months or more since I was offered a visual, and what a day!' The Captain was ecstatic, like a teenager on a motor bike, and he only had half a year to retirement!

'Godammit, I haven't done one of these for over a year, you jammy-assed bastard.'

Jim's North American vocabulary would never let you down.

Fun it might be, but an observant onlooker would have noticed that things were starting to happen, everything was now on fast forward. The atmosphere on the flight deck had thickened, a sense of pleasure, yes, relaxed yes, but something tangible was there; you could touch the urgency.

Mike at the controls, with the autopilot still engaged for the moment, had wound up the speed, the aircraft was accelerating rapidly towards 380 knots indicated airspeed. With the first indication that a visual approach might be on, through all the jocularity, his brain had dropped down a 'cog' and had begun to rev at high speed, the professional was at work …

Why, you may ask, this change, this metamorphosis, what is it all about?

The reason is quite simple. The crew had planned for an Instrument Guidance Approach, an IGS, which basically required the aircraft to cross over a beacon, the CH, situated on Cheung Chau Island at around 8,000ft and at a speed of 250 knots, or thereabouts. With the visual approach, especially one through the Lamma Channel, the track miles to touchdown had been drastically reduced. This meant the aircraft, or rather its crew, had much less time to get rid of the height, much less time to calculate, less time to think.

A new plan had to be devised and quickly. So the first action was to dive off some of that height, hence the increase in airspeed. Having done away with the excess altitude, the next problem would be to decelerate the aircraft. This would not be too difficult today as the aircraft was light. Surprisingly, to the layman, the heavier an aeroplane is, the further it will glide and, not surprisingly, the harder it is to slow down. Even 8,000ft at Tathong was a bit high, especially if you were carrying more than 300 knots.

'Passing 150 for 8,000!' Jim's voice was strident in order to ensure the Captain heard his check call over the now roaring wind noise.

'Check 150 for 8,000, setting QNH 1010, now passing level 142.' Mike's acknowledgement was loud and clear as he reset his altimeter to the regional pressure setting.

'That checks, QNH 1010 set and cross checked.' Retorted the first officer. It sounds simple enough, but many a hull has been lost because the crew had set the wrong pressure setting on their altimeters. Sound procedures and adherence to them

(Above) **Having carried out the tight turn into Kai Tak, an All Nippon 747 Freighter lines up on Runway 13 for landing.** Graham Dinsdale

A Cathay Pacific 747-467 on finals to Kai Tak. Rolls-Royce

are a great enhancement to flight safety. That is what this little ritual was all about. They where now only 20 nautical miles from Tathong Point, they still had 6,000ft to dispose of, and all that speed, it was going to be tight!

With 15 miles to go Mike eased back on the stick, reducing the rate of descent, although there was still another 4,000ft to lose, but he had to get rid of some of that speed! With his right hand he reached out and grasped the spoiler lever, pulling ever so gently (don't want to spill those drinks) back, the panels on the upper surface of the great mainplanes began to rise, disrupting the airflow and reducing the lift. Now, by raising the nose of the aircraft he compensated for the loss of lift but increased the drag. Like a powerful hand, the turbulent airflow grabbed at the airspeed and the knots began to fall away rapidly. They cross Tathong at 10,000ft but the speed was decreasing through 280 knots, soon they would be below flap limiting speed when other drag devices would come into play.

'Cathay 403, do you have Cheung Chau in sight?' The approach controller was checking their ability to continue with the visual.

'Affirm, Cathay 403, CH in sight' Was the clipped reply.

'OK, 403 you are clear up the Lamma Channel for the visual approach.'

The first officer gave a brief acknowledgement, he now had other work to do.

'Autopilot disconnected, flight directors away, Jim.' Jim switched off the instruments

(Top) **A Cathay Pacific 747-267B about to touch down in 1996.** Graham Dinsdale

(Above) **This 747 is down, heavily, but has just missed the white touchdown 'box'. On 4 November 1993 a China Airlines' 747-400 (B-165) ran off the Kai Tak runway after landing in heavy rain and strong winds caused by a nearby typhoon. The pilot quickly ran out of runway and tried to turn B-165 90 degrees onto the taxiway at the end of the runway, but without success, and the aircraft slid backwards into the waters of Victoria Harbour. Fortunately, thanks to the inbuilt buoyancy and strength of its construction, it refused to sink and all 296 passengers and crew escaped without any serious injuries.** Graham Dinsdale

leaving the Captain with little in the way of electronic aids.

He didn't need them, he didn't want them, they would only be a distraction, although the DME (distance measuring equipment) would be handy for distance to touchdown and that would be prominently displayed on the navigation display TV screen.

Mike was now hand-flying the aeroplane in a gentle right-hand turn with the thrust levers back at idle. Stretched out before them was a wonderful panorama, the whole of the British territory was laid out like one of those topographical models used to show the attributes of fancy housing projects. The visibility was unusually good with only a trace of the yellow pollution layer that so often blighted the view. From Macau to Shenzen it was as clear as a bell. Not that either crew member had time to sit and ponder, they were both looking at Green Island, just off the Western end of Hong Kong Island, thinking how close it was. They needed to cross abeam this point at around 3,000ft, not much higher or they would be looking at an embarrassing 'go-around'!

Mike eased in the spoilers, gently so as not to alarm the passengers with the accompanying trim change, and called for the first flap selection. The aircraft burbled as pneumatic pressure forced out sections of the leading edge flaps, increasing the lift, disturbing the airflow and allowing it to fly safely at a lower airspeed.

'Flap 5; Flap 10; Flap 20.' The Captain called the flap in sequence as he reduced the speed further. The first officer obliged, acknowledging each selection.

Adrenalin flowed, heart rates were up in the 160 region. Must get that height off!

'Gear down.' Mike needed more drag.

Now the aircraft really did rumble and roar in protest as the huge doors in its belly opened and disgorged the 16 big main wheels on four 'bogies', with the nose wheels, making a total of 18, a lot of rubber, courtesy of Messrs Goodyear Ltd.

Now at 220 knots with gear and flap 20 extended, the big machine fell like a stone, they were going to make that gate at Green Island.

The tension eased, Jim sat the cabin crew down and Mike called for the landing check-list. Another of those quaint rituals common to aviation, that have served to make the safest form of transport on Earth.

With Green Island approaching fast, Mike slowed the rate of descent, bringing the speed back steadily towards the flap 20 target. Anticipating, he eased the thrust levers forwards bringing the power up, carefully to make sure the thrust was balanced across all four of those huge Rolls Royce RB211s. The speed stabilized at 160 knots, there was little trim change.

FINALS TO KAI TAK

Kai Tak Airport had very definite terrain problems, which ruled out a standard ILS (instrument landing system) approach and presented pilots with an interesting landing pattern, to say the least. A straight-in approach towards the south-east was not possible because of mountains, primarily Lion Rock, lying to the north. Instead, when landing on Runway 13, an approach was made initially on a system similar to an ILS but offset at 47° to the runway, and referred to as an 'instrument guidance system' (IGS).

The IGS signals were rejected by pilots at about 700ft (215m) and the aircraft was flown towards a large red-and-white checkerboard at the foot of Lion Mountain, before commencing a sharp 40° turn onto the runway at about 500ft (150m). The IGS had a paired DME (distance-measuring equipment) with a built-in delay, which gave distance to the landing threshold, and on the ground, strobe lights marked out the turn with offset PAPIs (precision approach position indicators) indicating glide path. (In Hong Kong, only aviation danger and guidance lights are allowed to flash. All commercial advertising lights must be steady.)

With the completion of the new Chek Lap Kok International Airport, the approach into Kai Tak is no longer. On 6 July 1998 Cathay's 747-467 B-HUJ was the first airliner to land at Check Lap Kok, after a record-breaking world distance record for the longest commercial flight, from New York, over the North Pole, a distance of over 6,582 miles (10,590km) lasting 15 hours and 24 minutes.

Every time he flew it, the Captain marvelled at how beautifully the big aircraft handled. The pitch was light, the ailerons powerful and precise, the whole package so responsive to the sensitive touch. Just like a much smaller aircraft, this was no machine to be brutal with, it required caressing. It had no vices and loved to be flown, such harmonization Mr. Boeing had not achieved before.

'Cathay 403, call passing Green Island on Tower, good day.'

With a brief acknowledgement, Jim switched the radio onto 118.7 megahertz, the tower frequency.

'Good morning Cathay 403, you are clear to land, Runway 13. Surface wind 190 at 12 knots, QNH 1010.

Jim acknowledged and then joined the Captain in his visual search for the Kowloon Magistracy and the 'checkerboard'. They were somewhere out there, buried amongst all that expensive high rise.

Over Stonecutters now and bang on target. 'Give me flap 30 and complete the landing check-list, Jim.' They completed the ritual.

1,200ft, check-list complete and 155 knots, everything was 'hunky dorry'. Remember that windshear!

The checkerboard stood before them like dogs' whatsits now.

Allow for the wind, start the turn just that little bit early. Don't get blown through the centre line, it looks bloody awful. Every approach was a matter of professional pride, flown as though the whole world was watching, stacked with self-criticism.

'500ft, plus 10.' The first officer made his safety call and with his North American exuberance added 'Looking real good!'

The 747 was in the right turn with the wing tip appearing to scrape the apartment blocks. And right there, sure enough was the washing, on the line, hung out to dry and being doused in aviation paraffin. Poor old Mrs. Wong, she won't be sorry when they move to Chek Lap Kok!

The aircraft was bouncing about as she met those swirling dragons off Hong Kong Island, the speed was up and down 10 knots and this was a quiet day – what about in typhoon conditions? But that is another story!

Hands relaxed, small, rapid control movements, try to leave the power alone and look for the far end of the runway.

A large black kite, scavenger of the East swept past only a few yards away, a bit close for comfort, he tumbled in the vortices. An every present hazard, ingest one of those and your Royce may stop rolling.

The animated voice from the radar altimeter, agonizingly American, '60ft, 10ft.'

Mike had eased back on the stick putting the aircraft into the landing attitude. Hold it and ease the power off. She touched down like a cat peeing on velvet and the spoilers deployed automatically, killing all that lift and sticking her firmly to the tarmac. A touch of reverse thrust, save the engines but make sure it is there, just in case. Automatic braking did the rest.

They turned off the runway, 'cleaned up' the aircraft and taxied to the terminal. Time for a beer but don't forget, 'Like the man leaving the toilet, the job is not finished till the paperwork is complete!' Oh that bloody paperwork.

CHAPTER ELEVEN

Wings Across the Prairie

From the Flight Deck

Rain and strong winds hardly make a trip to the office any more enjoyable on a Monday morning, especially when heavy traffic and delays cause added frustration. However, knowing that your office will soon be at 30,000ft (9,000m) and heading 4,941.55 statute miles (7,951km) westwards from Gatwick Airport, London, to Denver, Colorado, via snow-covered Iceland and Greenland, does offer compensations! On 1 March 1999 G-BNLR, formerly *City of Hull*, one of a fleet of fifty-seven British Airways' 747-400s, had the honour of flying the first BA 747-400 flight into Denver International Airport.

British Airways is the world's biggest carrier of international airline passengers, and has a scheduled route network covering around 170 destinations in almost eighty countries. On average, a BA flight departs from an airport somewhere in the world every ninety seconds, contributing to a total of over a quarter of a million flights in a full year, carrying over 30 million passengers and half a million tonnes of cargo. BA is one of the leading operators of 747 series aircraft, introducing the first of its 747-100 series aircraft in 1971, and the 200 series in 1977.

On 15 August 1986, the airline placed its initial order for sixteen 747-436s, and by the summer of 1988 this was increased to nineteen firm orders, with options on a further twelve aircraft, an investment of $4.3 million each, the highest value aircraft order ever placed up to that time. In July 1990, BA signed their biggest ever contract with Boeing, for up to thirty-three additional Series 436 aircraft (twenty-one firm orders, plus options on a further twelve) valued at about $6.4 billion. (Not surprisingly therefore, on average, each 747-436 is in use 14.42 hours every day – an average of 4,900 hours' utilization per year – while the Series 100 aircraft is used 11.34 hours per day, and the Series 200 10.84 hours per day. The airline's last remaining 100s were gone by the end of 1999, and the 200s were due to be withdrawn by 2002.) In early July 1989 British Airways' crews began training on their first 747-436 (G-BNLA), and the company introduced the aircraft on its routes at the end of May 1989.

The captain of Speedbird 2019 (otherwise known as G-BNLR *Rendezvous*, formerly *City of Hull*) for the inaugural Denver flight, 1 March 1999, was 49-year old John R. Downey MRIN, flight manager 747-400 Fleet, who had over thirty years' commercial airline experience, including 4½ years piloting Concorde. Here he explains the routine:

For operational reasons, the Triple 7s [Boeing 777s] have been substituted by 747-400s for six weeks. We operate the 747-400 as a two-crew

British Airways' 747-436 G-BNLR Rendezvous **(formerly** City of Hull**), waits at Remote Stand 65 at rain-lashed Gatwick prior to the 9½-hour flight (Speedbird 2019) to Denver, Colorado.** Author

Captain Downey and Snr 1st Off Alan Emery go through their pre-flight check-list. These duties are divided between the 'handling pilot' and the 'non-handling pilot'. For the flight to Denver the handling pilot was Alan Emery, and Captain Downey was the non-handling pilot, so the latter performed the scan check and prepared the performance calculations, while the senior first officer programmed the flight management computer with the route and appropriate performance data. Then the two pilots come back together as a team to read the check-lists and to go through various procedures. The check-lists confirm that the data that has been loaded is correct, and that the pilots are prepared for engine start. Author

aircraft – captain and co-pilot – to operate the aircraft under normal circumstances. All the drills and so on are planned around that crew complement, but on longer flights, to provide in-flight rest, we carry either one extra member or sometimes a complete double crew, depending on the length of the flight. [The primary crew is referred to as the 'operating crew' and the secondary crew is known as the 'heavy crew'.] Denver is such that it triggers one extra crew member. We have three members so that we can play 'musical chairs' and get some rest during a long flight. [It is standard procedure for the operating crew to fly the 747 for the first few hours of the flight, while the third pilot rests, and each can do this by either taking a nap in one of the two bunks in the cabin immediately behind the flight deck, or one of the very comfortable, fully reclining seats in Club Class.]

The CAA lays down rules and regulations for how long you can fly with a two-crew, a three-crew or a complete double crew, and there is also an industrial agreement between the company and BALPA [British Airline Pilots Association], the pilots' union, which also controls the crew complement. [The over-riding legal restriction for flight crew is 100 actual flying hours in any twenty-eight-day period.] A short trip from say, London to New York, would be a two-crew operation, but as the flight extends out to Denver, where flight time is over nine hours, we require three, and if we are going to Buenos Aires or Singapore/Australia, then it would require a double crew.

The crew will bid for their work, and they do this about a month ahead of the normal schedule. When they've got their trips, that's their planned roster for the month. Because the Denver operation is a substitution for a Triple 7, the trips went into the system relatively late and in fact one of the two co-pilot slots was not covered until the day before the flight and someone available was given it.

This slot was filled by Dominic Boyle aged thirty-four, who until 2½ years before was a No.70 Squadron RAF Hercules pilot. Captain Downey's senior first officer for the Denver trip was Alan Emery (forty-six), a pilot with over twenty years' flying experience. Although Captain Downey is in overall command of the flight, the operation of the 747-400 is a team effort. Apart from the flight crew, the sixteen cabin crew are on board to help ensure the safety of, and to look after the 401 passengers seated in First (fourteen passengers), Club World (fifty-five) and World Traveller (332) (British Airways does not use the word 'class'). The captain and first officers are required to complete a set number of take-offs and landings over given periods to maintain their currency. This is quite difficult to achieve on the long-haul direct flights, such as Gatwick to Denver, where flying hours often reach double figures (9½ hours outbound, and about 9.02 hours inbound). To qualify for a flight, it might be necessary for a pilot to operate the flight simulator if he or she has not carried out a landing within the last twenty-eight days. For the same reason, automatic landings are only carried out when it is necessary, since only manual landings keep the crew member qualified.

Captain Downey continues:

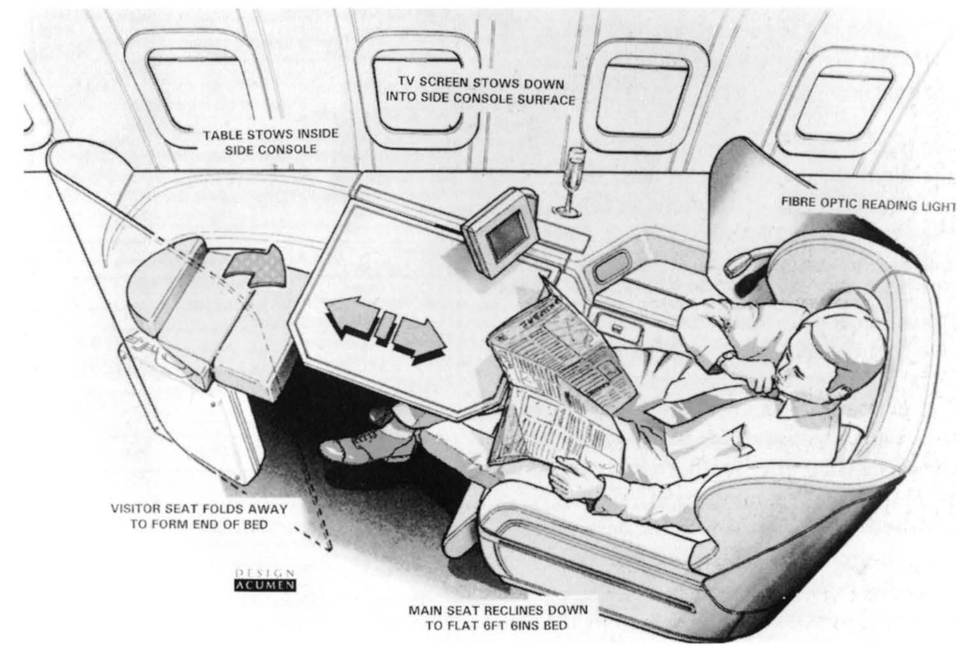
The crew meet at a report centre at Gatwick and receive their briefing. Some of this is prepared and the briefing officer would just hand most of the paperwork over for self-briefing. [A comprehensive briefing summary is given to the captain for flight BA 2019 on a ten-page computer printout, together with another ten-page printout giving up-to-date local weather at all the airfields and alternates along the route.] One of problems we had was that the computer system we use to check in to actually acknowledge the fact that we'd turned up for the trip, was unserviceable, which caused lots of other problems. Eventually, we got all our paperwork. At that stage we look at the AIS [Aeronautical Information Service] information, and the weather information for our flight. This is collated into one document by British airways systems and is called the 'New Brief'. That has all the NOTAMS and the meteorological information that we require for the flight. It's fine-tuned, filtered if you like, so that we do not end up having to look at every single piece of information that might be picked up on NOTAMs for Gatwick. It will just be the things we are interested in, and it's the same for all the other airports on the route. That document is still quite long for a flight to Denver. The flight plan itself has already been computed using a system call SWORD, a computer system which resides in our reservations mainframe computer using the same language. The system takes meteorological data from Bracknell, Berkshire, and Washington, for all the upper winds. [Both met. Offices have a Cray computer which runs a mathematical model of the upper wind data for the whole of the world. Each can carry out several billion floating-point calculations a second. They 'talk' to each other, and provide back-up for each other as well.]

This, then, gives all the meteorological information we need. Load control will have worked out how many passengers they have got, and the dispatch process will know what weight, and what payload, the aircraft is looking to carry. That will be fed into the flight planning system along with the wind conditions on the route that will give us the fuel required. We look at that, and also at the structure of the reserves that are given to us (that's because we need sufficient fuel to fly from Gatwick to Denver, but we also need sufficient fuel for any en-route contingencies that may occur. For example, there could be delays at the airport, and the winds may not be quite what we expect. We also have to have sufficient fuel to fly from our destination to a suitable alternative, which for the Denver flight is Salt Lake City, Utah. So, all that added together comes up with the final fuel figure required – just under 120 tonnes. [Annually, British Airways uses six million tonnes of fuel, costing between £150–£400 per tonne; the cost of which is second only to salaries.] We then confirm that that is the amount of fuel we require, and that is then signalled out to the aircraft support team at the gate who would make sure that the refueller knows that figure and they would start pumping fuel. This all happens at departure minus one hour.

It was a day that did not start terribly well. Because of a bus delay, we actually arrived at the aircraft [at Remote Stand 65, far enough away from the North Terminal that both passengers and crew have to be bussed out to the 747], about thirty-five minutes before departure. Normally it is fifty-five minutes before departure. [This, and a technical problem with an engine fire detection loop resulted in about an hour's delay getting the 747 away. Take-off was originally scheduled for 10.35am, and during the delay and long taxi out, Speedbird 2019 burned about a thousand kilograms of fuel. This in itself was not a problem because a corresponding amount of fuel is always allowed for in the fuel plan at briefing.]

When we arrive at the aircraft we have various checks to perform. One of the team [usually the pilot who is flying the aircraft on the route, i.e. the take-off and landing] will walk around the outside of the 747 and ensure that everything is serviceable, making sure that no trucks have been moved into the side of the aircraft, that no pitot head covers have been left on, that the tyres are in good condition, that there are no hydraulic leaks, and so on. It is the same as a walk round on any other aeroplane, really.

Meanwhile, if, on arrival in the cockpit, the ground engineers have not activated



BA's revolutionary First service offering individual cabins. BA

the 747's electrical and air supply, this will have been done by the crew. A safety check will have been made to ensure that the hydraulic pump selectors are off, the landing gear lever is selected 'down', and that the flap-lever position selectors agree. On the flight deck, the three inertial reference systems (IRS) are selected to navigation mode (NAV). Then the crew perform the cockpit pre-flight systems and equipment check, otherwise called a 'scan check'. Captain Downey explains:

> Basically, this is done using the instrument panel itself as a check-list, and scanning around the panels in a pre-determined order, making sure that all the switches are in the right place, prior to departure.

For the overall systems checks, the on-board computers combined with the EFIS (electronic flight instrument system) displays can be used for determining serviceability. Each check is called up on the EFIS and has to be satisfactory before the crew move on to the next item. Because just two flight-crew operate the aircraft, the flight engineer duties have been built into the computers. The primary flight instruments are duplicated for both the captain and the first officer so that either can fly the 747, and the communications and systems are located centrally for easy access by both crew. Generally, the communications and navigation controls are located on a central console between the pilots, while the aircraft systems, such as fuel flow, air conditioning and electrics and so on, are mounted above the pilots in the cockpit ceiling. Additional controls on the central panel are for the Rolls Royce RB211-52224H engines, including thrust levers, starting and fuel cocks, plus trims for the ailerons and elevators. Captain Downey continues:

> The duties are divided between the 'handling pilot' and the 'non-handling pilot.' For the flight to Denver the handling pilot was Alan Emery, and I was the non-handling pilot, so I performed the scan check and prepared the performance calculations, while Alan programmed the flight management computer with our route and appropriate performance data. Then we come back together as a team to read the check-lists and to go through various procedures. The check-lists confirm that the data that has been loaded is correct, and that we are prepared for engine start. It means going through all sorts of things, basically a cross-checking process. That one person has loaded the route and someone else checks it, ensures that the distances between each position are correct, and so on. It is quite a detailed cross-checking process, not necessarily for the whole route at this stage, but for sufficient so that we have time to go back

BOEING 747-400 NORMAL CHECKLIST

COCKPIT SAFETY CHECK	
Battery Switch	ON
Standby Power Switch	AUTO
Hydraulic Demand Pumps	OFF
Windshield Wiper Switches	OFF
Alternate Flap Selector	OFF
Landing Gear Lever	DOWN
Flap Position Indicator & Lever	AGREE

BEFORE START	
Int/Ext Preparation	COMPLETED
Oxygen	CHECKED/100%
Flight Instruments	SET
QNH/Aa	SET/CROSSCHECKED
Park Brake	SET
Fuel Control Switches	CUTOFF
Autobrake	RTO
Passenger Signs	AUTO
----- Briefing -----	
AIS & DDM Items	
Runway State - Significant Weather	
Emergencies - Performance Restriction - Return Alt	
SID - Radio Aids Set - AFDS (LNAV, VNAV, Hdg, Alt)	
Terrain Clearance - Transition Altitude	

CLEARED FOR START	
Hyd Demand Pump No. 4	AUX
Hyd Demand Pump No. 1	AUTO
Fuel Load & Pumps	CHECKED & SET
Packs	ONE ON
Beacon	ON
Doors (Prior to pushback)	CLOSED

AFTER START	
APU Selector	AS REQD
Anti-ice	AS REQD
Aft Cargo Heat	ON
Air Conditioning	SET
Recall / Status	CHECKED
FMC	UPDATED
T/O EPR	SET
Ref Speeds	SET
L.Nav / V. Nav	AS REQD

BEFORE TAKE OFF	
Vital Data	RELEVANT
Flaps	( ) GREEN
Flight Controls	CHECKED
Trim	UNITS & ZERO
Transponder	SET
Cabin Crew	REPORT RECD
----- Entering Runway -----	
Exterior Lights	AS REQD
Cabin Crew	SIGNAL

AFTER TAKEOFF	
Landing Gear	UP & OFF
Flaps	UP
Air Conditioning	SET
Nacelle Anti-icing	AUTO
----- Trans Altitude -----	
Altimeters	STD/CROSSCHECKED

DESCENT BRIEFING
Safety Altitudes - Trans Level
U/S Items - Sig Weather - Handling Pilot
STAR - Approach
Runway State - Reverse - Brakes
Airfield
Go-Around - Diversion

DESCENT/APPROACH	
Recall	CHECKED
Briefing	CONFIRMED
V_{REF}	SET
Minima	SET
----- Trans Level -----	
Altimeters	QNH/CROSSCHECKED

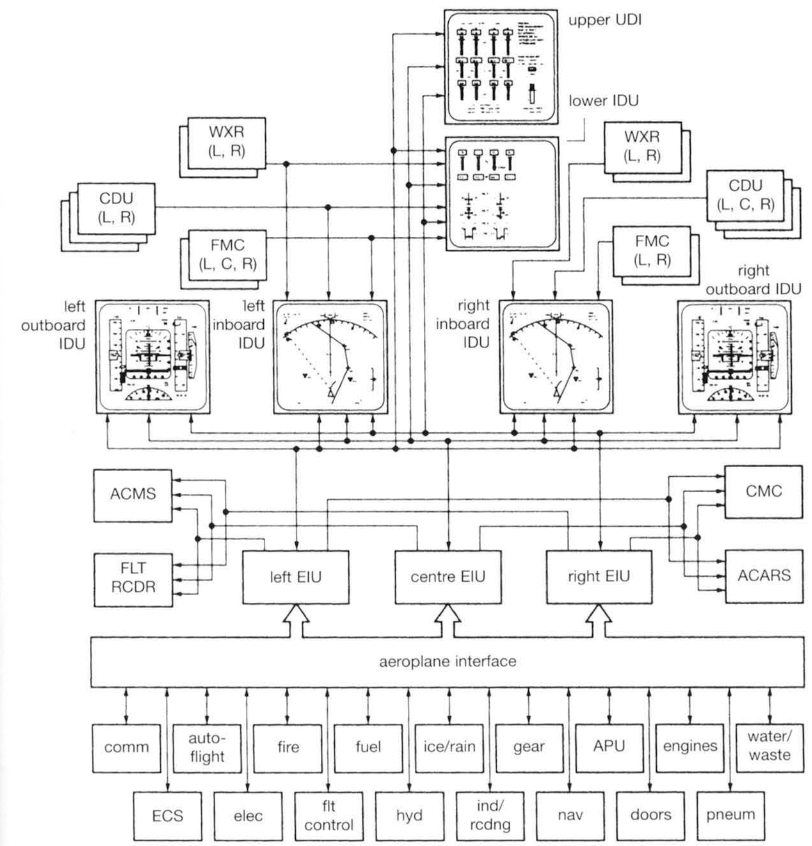
LANDING	
Speedbrake	ARMED
Autobrake	SET
Landing Gear	DOWN
Flaps	( ) GREEN
Cabin Crew	REPORT RECD & SIGNAL

AFTER LANDING	
Strobes	OFF
Stabilizer	6 UNITS
Speedbrake	DOWN
Flaps	UP
APU Electrics	AVAIL
----- Approaching Stand -----	
'Doors to Manual'	CALLED

SHUTDOWN	
Hyd Demand Pumps	OFF
Fuel Pump Switches	OFF
Aft Cargo Heat	OFF
Wx Radar	OFF
Park Brake	AS REQUIRED
Fuel Control Switches	CUTOFF

SECURE	
IRS	OFF
Emergency Exit Lights	OFF
Packs	OFF
APU	OFF
Ext Power	OFF
Standby Power Switch	OFF
Battery Switch	OFF

747-400 normal checklist.



Integrated display system *(left)*.

Management of flight systems is accomplished on the flight deck through the integrated display system (IDS), which compromises the EFIS and the EICAS. The IDS features six identical integrated display units (IDU), which are 8 × 8in (20 × 20cm). Two of the units are EFIS primary flight displays (PFD), two are EFIS navigation displays (ND) and two are EICAS displays.

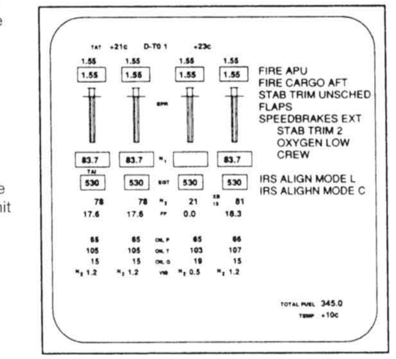
The PFD and EICAS primary formats automatically switch to inboard and lower IDUs respectively. The pilots can also manually select formats on different IDUs as required.

All IDUs receive data from all three EFIS/EICAS interface units (EIU). These units also store and transmit fault data for the central maintenance computer (CMC). Software updates for all of these systems may be loaded with the software data loader.

Crew alerting system *(right)*.

Continuous monitoring of all aeroplane systems is performed by EICAS. Alerting messages are shown on the primary display unit with their degree of urgency indicated by colour and associated aurals.

Compacted display mode for EICAS, shown here, brings all main and secondary display information onto a single CRT. This will occur if one EICAS display unit fails.

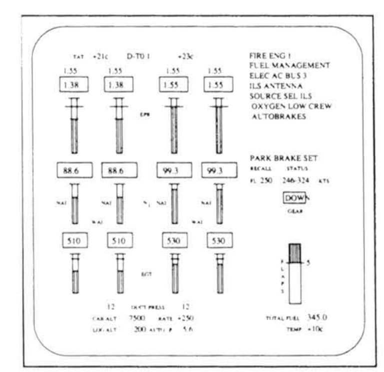


EICAS compacted display

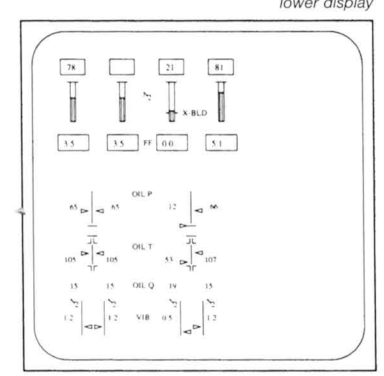
Message levels break down in the following way: Warning signals are red[a] and indicate an operational or aircraft system condition that requires immediate corrective or compensatory action by the crew. Caution signals are amber[b] and indicate an operational or aircraft system condition that requires immediate crew awareness and future compensatory action. Advisory signals are amber and indicate an operational or aircraft system that requires crew awareness and possible future compensatory action. Status signals are white and indicate minimum equipment list-related items requiring crew awareness prior to dispatch only. Memo signals are white and indicate crew reminders of the current state of certain manually selected normal conditions.

[a]Associated with aural warning siren or fire bell, master warning lights and dedicated system-warning annunciators.

[b]Associated with aural caution beeper, master caution lights and dedicated system-caution annunciators.



upper display



lower display

Engine indication and crew alerting system *(left)*.

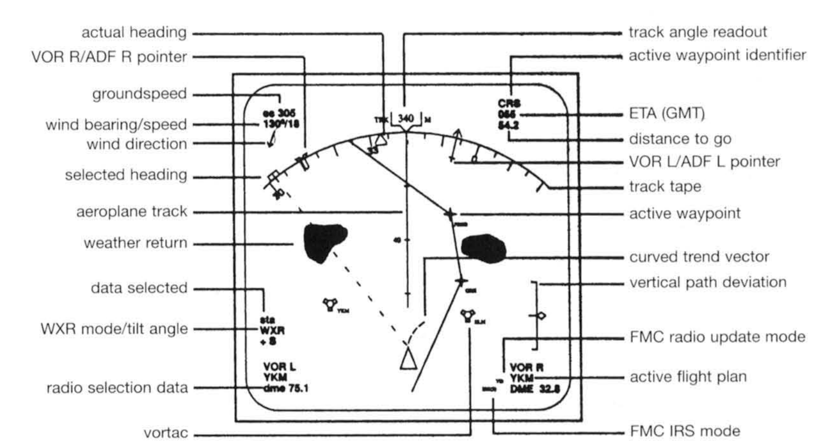
The *upper display unit* normally displays the primary engine parameters.

Information shown on the primary engine indication and crew alerting system (EICAS) display comprises:

1. Total air temperature.
2. Primary engine indicators, which include engine pressure ratio (EPR), N1 rotor speed and exhaust gas temperature (EGT).
3. Thrust-mode data.
4. Selected assumed temperature.
5. Inflight start information.
6. Duct pressure.
7. Cabin altitude and pressure data.
8. Landing altitude.
9. Total fuel quantity.
10. Fuel temperature.
11. Flap-position indications.
12. Landing-gear indication.

The *lower display unit* normally displays:

1. N2 rotor speed (N3 for RR).
2. Fuel flow.
3. Oil pressure.
4. Oil temperature.
5. Oil quantity.
6. Engine vibration data.

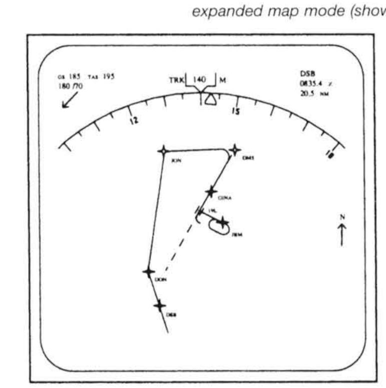


expanded map mode (shows 80° of the compass rose)

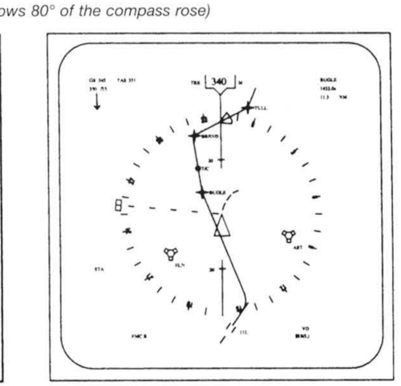
Navigation display map and plan mode *(right)*.

Airplane orientation information is shown on the top portion of the navigation display when it is in the plan mode. The lower portion of the display shows the flight plan, with north at the top, as it is stored in the flight management computer.

Map mode displays show the portion of the flight plan that is within a specified range. The maximum range that can be shown is 640 nautical miles. Either VHF omnidirectional range (VOR) or the automatic direction finder (ADF) may be displayed in pointer form on the compass rose.



plan mode



centre map (shows 360° of the compass rose)

into it in detail once we are in the cruise. You have at least made sure you are covered, up until entry into oceanic airspace. Quite often the routes are changed once you are in oceanic airspace anyway.

We then go into negotiating with ATC (air traffic control), which can be quite protracted. This is because aircraft going in particular directions have slot times, which is a way of controlling the number of aircraft in particular bits of airspace. In Europe, a particular bit of airspace or area can only accept a certain number of aircraft at a time. One of the ways of controlling congestion is by only allowing aircraft to take off for, say, Brussels, at a particular time, so there is always a gap in the airspace for the aircraft to enter. This means that aircraft that do not have particular constraints – and we were one of those – end up being pushed to the back of the queue. Gatwick is, to be honest, creaking at the seams: there is just one runway, but as many movements as at several large international airports with multiple runways.

To add to the frustration, when we finally managed to get everything sorted out and on our way we had a minor technical problem: one of the fire detection loops on one of the engines was found to be unserviceable. The system is a dual logic system, so that if you have two loops working, you have to get warning on both of the loops to confirm a fire. If you have just one loop giving a warning it is considered a fault. When you have only one loop active, if that fire loop detects a warning you get a fire warning. Basically it means you could get a possible false warning. However, it is a perfectly acceptable thing to despatch the aircraft with.

Once we get clearance to start up and push the aircraft back from the gate, we then go into another check-list, to make sure that we have got appropriate hydraulics systems pressurized (to provide braking and steering for the body gear). Then we push the aircraft back and start the engines. These are started by the non-handling pilot; the handling pilot basically just keeps an overall watch on what's going on, and communicates with the groundcrew initially, and the pilot starting the engines talks to the groundcrew while the engines are actually starting. [The engines are started in the sequence: four, three, two, one, as number four engine normally powers the hydraulics which supply the main brakes.] We have a system on the 747-400 called Autostart, which enables us to start two engines at a time. The system automatically selects fuel and monitors the start sequence, and will take action if any start malfunctions occur. On previous Jumbos we had to actually monitor the engines ourselves. Usually, the engines on the Classic were started by the non-handling pilot and the flight engineer working together. The APU's [auxiliary power unit] pneumatics provide the air for starting the engines. [The APUs on the -400 consist of two small turbine engines located in the rear portion of the tail-cone, which exhaust to the rear, driving two generators. With this unit running, electrical power is provided for the aircraft systems, including air-conditioning and cabin lights to either cool or heat the cabin.] If something like the EGT (exhaust gas temperature) gets too high [the maximum is 700°C] during the start, it will automatically cut the fuel off and cool the engine down before trying to restart it. If, for some reason, it is unsuccessful, it will come up and say 'I've tried my best and can't cope'. We would then look to do something manually. It is a very good system, and it means that a very large aeroplane like a 747-400 can have all four engines running very quickly as we push back.

As soon as the tug puts us in the position where he wants to disconnect, we have usually reached the stage where both pairs of engines are running. We then get clearance to taxi out, which is usually given as a sequence of coded letters for the appropriate taxiways, either numbers or letters (at Gatwick it is numbers). You have to make sure you taxi out on the centre lines you are supposed to, and on a congested apron it is also important to keep a very good look out [three pairs of eyes are used here] to make sure you don't have something parked where it is not supposed to be parked. Once you get out into more open taxiways, it is usually not a problem. There are lots of other aircraft around at Gatwick – it's a very crowded place; even when you get out to the holding point (they have four different holding points at Gatwick to allow planes to overtake each other to meet various take-off departure constraints) it is quite a complicated area.

One of the other things you have to be very careful of with a large aircraft is the amount of thrust that you need to move. Exhaust velocity is significant, and you have to be very careful about where you point it. If you are turning away from the terminal, with the exhausts of the engines pointing towards it, it is very important that you have only idle power on, as the exhausts play over the building. Otherwise you could get into terrible trouble – you could blow a car over if you put too much thrust on. Certainly things like empty containers can blow around on very low power settings.

We get ourselves out to the holding point, and then we are just in sequence for departure, awaiting our turn. When ATC give us clearance to line up, we taxi onto the runway. At the same time we perform the last part of the before-take-off check-list – the last-minute items, configuring the air-conditioning system and switching on the appropriate lights, and warning the cabin crew that we are just about to take off. We do this by virtue of a chime that they can hear.

The air-conditioning is quite interesting. On all commercial aeroplanes with large fan engines the air is bled off the engines to provide air-conditioning. On the 747-400 we have three packs which provide air-conditioning, but of course when they are operating you are actually taking air away from the engines, which under normal circumstances is compressed and mixed with fuel to provide extra thrust. So for take-off, you don't really want to have the air-conditioning on at all, because you want maximum thrust. However, for passenger comfort it is quite nice to be able to have one air-conditioning pack on, because then you don't get the sudden step-change that you notice on some of the short-haul aircraft where the air-conditioning suddenly kicks in. What we do is to use air in the APU to run one of the packs, so we have one pack running and the other two packs switched off for take-off. Then once we are airborne and have made the power reduction to climb-power, we can reinstate the other packs and shut down the APU.

Once we are cleared for take-off, the technique is a matter of keeping the aircraft straight on the runway. You use what is called rudder fine steering; the rudder pedals also move the nose-wheel, so you use the rudder pedals in the same sense as you would to keep the aircraft straight with rudder, but that's also using the nose-wheel as well. Because there was a blustery wind and a slight crosswind, we also required a little bit of aileron into the wind to keep the wing level, and you pre-set this to a guesstimated amount, so that you can then modulate it. Effectively, we fly the wing level down the runway; as the gusts come and you see the wing try and lift, you push it back down again. You set the power by advancing the throttles manually until the engines have spooled up to a suitable stabilized power setting to enable you to accelerate the engines in unison.

The handling pilot (Alan) does the take-off and landing, and I will fly the approach into Denver, and hand over control for the landing. One person flies the approach for the other pilot. When you 'stand the throttles up' you advance the throttles just enough until the engines have accelerated to about 1.1 to 1.2 EPR (exhaust pressure ratio). The reason we do this is that when we apply take-off power, we get smooth acceleration of all the engines [each of the four RR RB.211-524Hs is capable of producing 60,300lb (27,350kg) thrust]. If we just put the throttles straight up to take-off power, one engine might well accelerate quicker than

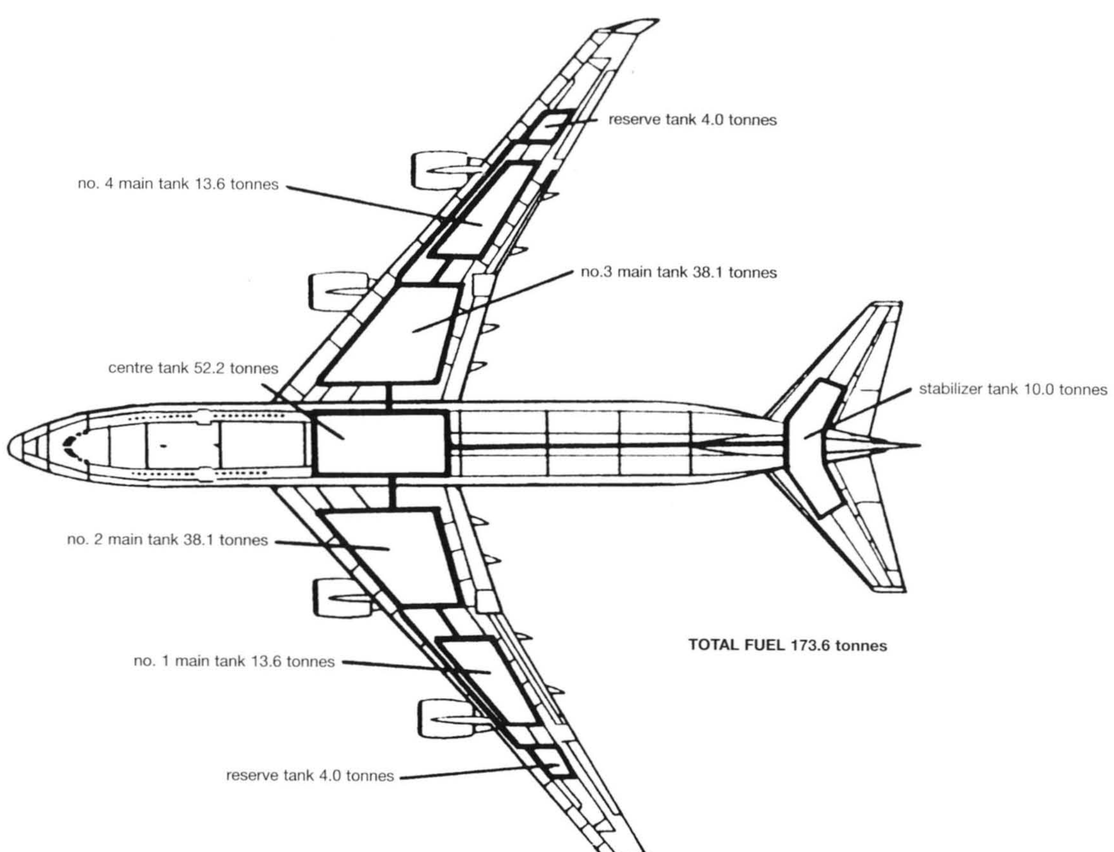
(Above) **Delays put Speedbird 2019's take-off back from 10.35 to 12.05 and in that time burned an extra tonne of fuel. After 'push-back' G-BNLR taxied out to Runway 26L. Virgin Atlantic's G-VMIA 747-123** Spirit of Sir Freddie **developed a technical fault just before take-off and had to return to its stand. This aircraft, the eighty-seventh 747 built, was delivered to American Airways in 1970 as N9669 and subsequently operated with Air Pacific (N14939), Cargolux (LX-NCV), Highland Express (G-HIHO), Qantas (VH-EEI) and Aer Lingus (EI-CAI), before being bought by Richard Branson's airline in 1990. At first VMIA was named** Maiden Miami, **and then in July 1992 it was renamed** Spirit of Sir Freddie **in honour of Sir Freddie Laker, a man who did more than most to promote cheaper air travel across the Atlantic.** Author

Finally, Speedbird 2019 is cleared to leave rain-soaked Gatwick to climb out and away up to the Moray Firth and Scottish Isles via the Midlands for its eventual departure across the Atlantic. 1st Off Alan Emery maintains the throttle levers as the altimeter shows 13,400ft (4,084m), and the airspeed indicator registers 350 knots. The captain's primary flight display (PFD), or the EADI (electronic attitude director indicator) (left) displays aircraft attitude, altitude, horizon, airspeed, vertical speed and heading. His navigation display (ND) or EHSI (electronic horizontal situation indicator) shows track, heading, wind and distance. (The display screens are reversed for the first officer.) The two engine indication and crew alerting system (EICAS) display units, located centrally, monitor the performance of various systems and alert the crew to any abnormal conditions. The plate next to the mode control panel above the artificial horizon which says 'This aircraft is H-rated' refers to the engine-power rating guaranteed from each 60,300lb- (27,350kg-) thrust RB.211-524H engine. Author

another from idle. You would end up with asymmetric power set, and end up doing a very quick pirouette on the runway! This has happened. People have left the paved surface, more so in the early days with the classic engines. The older Pratt & Whitney engines were erratic in the way that they accelerated; but stabilizing the engines is something that we still do because it is important that you get smooth acceleration. Those outboard engines are a long way out, and if one of these is at take-off power and the other one is not, you have not got enough steering at slow speed to control the direction. You advance the power, and the handling pilot just presses the take-off/go around (TO/GA) switches, and that then programmes the autothrottle to go up to the appropriate power settings. We derate power. We work out what the aircraft would actually take off at on that runway in representative conditions. If the aircraft is lighter than that performance limit, we can reduce the amount of thrust and this improves engine life. Basically, the hotter the engines get, the more effect on their life. If you can keep the thrust down and hence the turbine inlet temperatures down, the engines last longer. You don't have to do a 'wheel spinning get-away from the traffic lights' every time!

Once we are accelerating down the runway, the next thing to be looking at are the performance considerations – whether we can stop, or whether we have to continue. This is done during flight planning by calculating the speed to which the aircraft can accelerate (at its weight for the flight) and still be able to brake within the length of runway available. This speed is called 'V1' [V is for velocity]. It is also the speed at which, if one engine fails, you can still accelerate sufficiently to climb away safely from the runway on three engines. If the take-off has to be rejected at V1, the handling pilot closes the throttles, which engages autobrake RTO (rejected take-off): this routes full hydraulic pressure (3,000 psi) to the brake units. The brakes on a 747 are carbon-fibre, much the same as a Formula One racing car except that there are sixteen individual brakes, one on each of the main wheels, and the brakes are actually multiple disk and pad packs, so you have rotors and stators, all made of carbon and they are all clamped together by hydraulic pressure. So effectively, you have got a lot more disks than a Formula One car, even though basically it is the same sort of technology. The brakes have to absorb the energy for a rejected take-off of the aircraft at the maximum take-off weight of just under 400 tons and travelling at about 180 knots. You can imagine the amount of energy this involves: it is an awful lot of juggernaut (more than 100).

At V1 you are committed to take off. The handling pilot then removes his hands from the throttle levers and puts them on the control column. When we get to 'rotate' [VR] (we again use a calculated speed depending on the weight of the aircraft), the handling pilot initially pulls the column back smoothly to pitch the aircraft up to 12½ degrees; we do this over a period of about six seconds. If we rotate too quickly and pull the stick back sharply, there is a risk of striking the back of the aircraft on the ground; also, the aircraft will not accelerate to the correct speed, which is V2 (engine out safety speed), plus 10 knots. [VR and V2, calculated by the computer, are displayed on the flight management system (FMS)]. Conversely, if you rotate the aircraft too slowly it will accelerate too quickly and will be too high a speed, but also it will not climb quite quickly enough and therefore you would not achieve the required gradients. So it is quite a critical manoeuvre. And if you have got a crosswind at that time, you are also transferring from having aileron into wind, to hold the wing down, to allowing the nose of



747-400 fuel tank positions (not to scale).

Captain Downey and Sn 1st Off Alan Emery confer and study their data link printouts and calculations as G-BNLR proceeds from Lambourn to north of Birmingham and on over Nevis to Stornaway. Author

the aircraft to lay off drift, so that you fly along the appropriate path with the ailerons level.

You then follow the lateral navigation path that has been programmed into the flight management computer. If ATC want you to do anything other than the 'standard instrument departure; (or SID) that they have cleared you on, they will give a heading and you will then use the autopilot mode heading select to fly the appropriate heading. Also, at that point, vertical navigation is engaged and that will follow a pre-programmed acceleration, enabling you to retract flaps.

Out of London-Heathrow and London-Gatwick, we fly a specific noise abatement procedure, which means that at 1,000ft (300m) above the ground we reduce power to climb-power, and at the same time accelerate the aircraft to our Flap Ten speed plus 10 knots. We retract the flaps to Flap Ten and then climb at that speed. The take-off flap setting is twenty. Once we reach 3,000ft (900m), we then accelerate and clean up the aircraft by retracting the flaps, using the various bugs which we pre-computed on the speed tape on the left-hand side of the PFD. Once the aircraft is clean, then our speed is unrestricted by ATC. We also have to bear in mind that if the path we want to follow is a fairly sharp turn, that we do not accelerate the aircraft too quickly because obviously, the faster the aircraft travels, the greater is the radius of turn, and this might not be ideal in a crowded terminal control area. We then climb the aircraft using the computed speeds from the flight management computer (FMC), up to the cruising level. The handling pilot will then load in all the meteorological data on the various pages of the flight plan, so that the FMC can compute a proper ETA at the appropriate altitudes that we are going to fly for the whole of the flight.

The weight of fuel on this trip is 120 tonnes, and a large percentage of this is carried in the wings. When the flaps have been retracted, the fuel system automatically reconfigures so that the centre tank (which is effectively in the middle of the wing inside the fuselage) will be feeding all the engines. The reason for this is that we want to retain the weight of fuel in the wings to provide 'bending relief' (the weight of the engines mounted under the wings also helps relieve the stress in the wings) because obviously, when the 747 is airborne, the wings are producing lift, so the force upwards is bending the wings upwards. Any weight in the wings is bending them downwards, so the more you can keep them in balance, the more the structure is unstressed. So we consume the fuel in the centre tank first, and as the aircraft gets lighter it still has weight in the wings from the other fuel.

Once the centre tank fuel is consumed, we then burn fuel from the two main inboard tanks (tanks two and three) until they equal the amount of fuel in the outboard tanks (one and four). Just before we start running the aircraft on what is called 'straight feed' (when all four tanks are equal), the four tonnes in the reserve tanks, which are the most outboard tanks in the wings, is run into tanks two and three. This takes place just before we reach the straight feed configuration and basically, that is when there is enough room in the inboard tanks to take the additional four tonnes of fuel.

We fly on our routing to the east of London, towards the Queen Elizabeth Bridge, then back west again – moving up, past Trent, Manchester, Nevis, Moray Firth, and out towards the Western Isles and Stornaway. Our routing does

(Left) **It's 14.45 and at 33,700ft (10,270m) Iceland looms on the horizon. It is literally the icing on the cake for the flight crew, who have never seen Iceland this clear in the past thirty years. Ten minutes later the first pilot change is made when Dominic Boyle takes over from John Downey for his 'shift'.** Author

Greenland looks picturesque but distinctly uninviting as Speedbird 2019 passes majestically above the barren, rocky landscape at 34,000ft (10,360m). Outside air temperature at this height is –60°F (–51°C) – even the fuel temperature is –64°F (–53°C). (Temperature falls with altitude by about 3°F every 1,000ft (300m), reaching about –65°F (–54°C) by 36,500ft (11,125m) before rising slightly after this.) With the 747's cruising speed of Mach 0.84, the temperature differences between outside air and surfaces (which are warmed by friction caused by the high-speed airflow) are 158°F (70°C). Author

not take us into the oceanic area controlled by Shanwick (the amalgamation of Shannon and Prestwick) because we are routing into Icelandic airspace (we actually obtained our Oceanic clearance as we entered Icelandic airspace). We then route up over Iceland, getting a fantastic view of that, and then out over Greenland, before coming in over Labrador, Hudson Bay, and across the Canadian border into the United States and on to Denver.

As we have said, it is standard procedure in British Airways 747-400s that the handling pilot hands over the controls to the non-handling pilot for the descent, so in this case, as Alan Emery was going to do the landing, I took control of the aircraft for the descent, handing over to him again for the final landing. Again we programme the FMC to give us a vertical navigation profile which we follow, but in fact ATC were somewhat less than helpful and brought us above that profile – this resulted in an early selection of

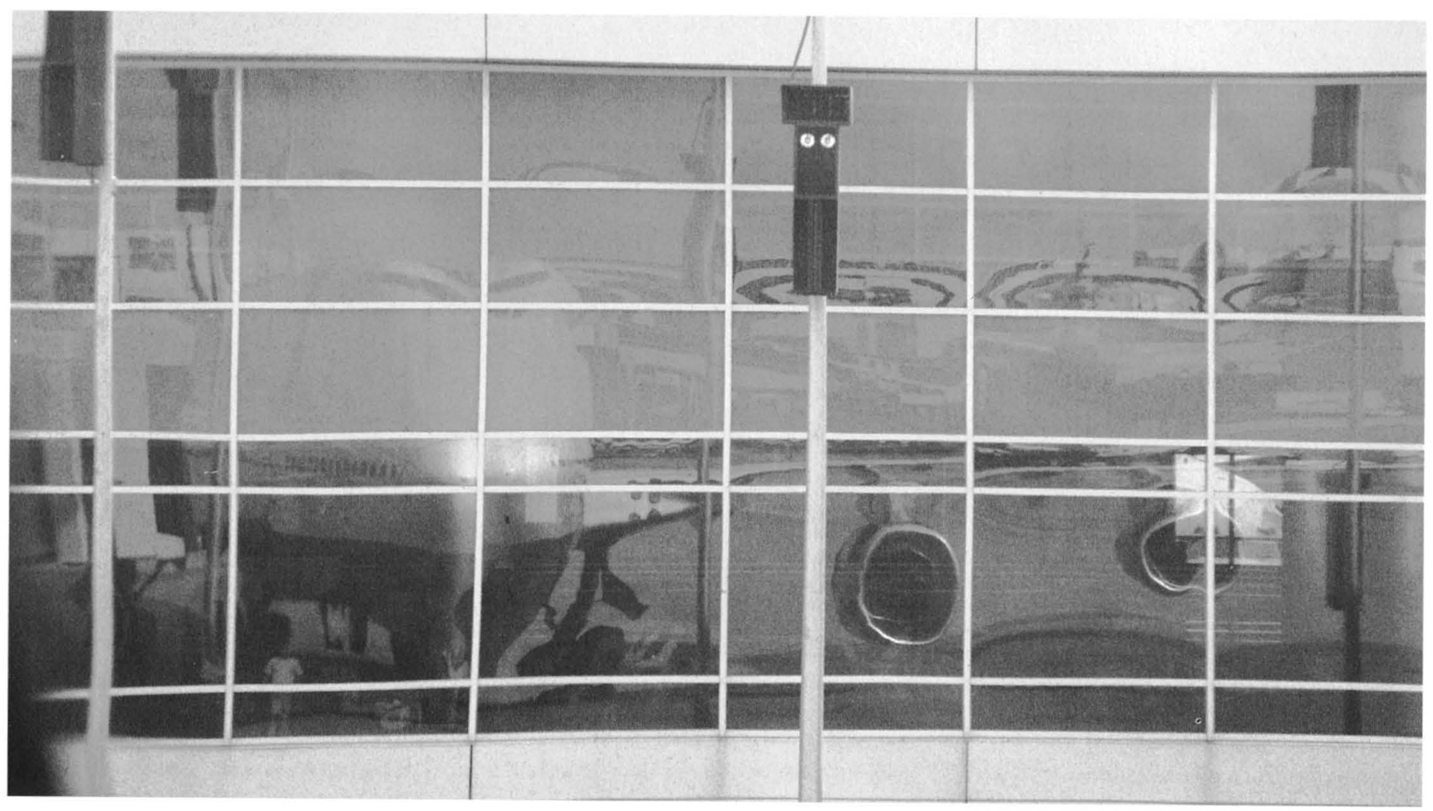
Captain Downey maintains a close watch as Alan Emery, who is flying the -400 manually after disengaging the autopilot and autothrottles for the descent, brings Speedbird 2019 into Denver. Captain Downey will take control of the aircraft at 50ft (15m) altitude for the landing. Author

the undercarriage to increase drag and enable me to increase the rate of descent to get back onto the proper profile. Once we were established on the ILS I handed over to Alan, who continued, eventually disconnecting the autopilot and the autothrottle for a manual, crosswind landing.

The reason we disconnect the autothrottle as well as the autopilot when we are manually flying the aircraft, is because under certain circumstances the autothrottle can destabilize the aircraft. For example, if you pitch the aircraft up, the drag increases as you ask for more lift. The speed starts decreasing, so the autothrottle would increase power. Now, with the 747, with the engines slung underneath the wing, this increase in thrust pitches the aircraft up. You therefore end up pitching up more than you want to, so you pitch down more. It ends up in what is technically called a 'fugoid'. If you actually control the throttles yourself, then you can co-ordinate more effectively.

With a crosswind landing, as Alan did an excellent job coming in on Runway 25 at Denver, you have the aircraft with drift laid off to maintain the extended centreline of the runway, and then as you approach the flare manoeuvre, at about 30ft (9m) above the ground, the aircraft is pitched up to reduce the rate of descent for a smooth touchdown, and then at the same time, a gentle squeezing of downwind rudder yaws the aircraft round so that the fuselage is pointing down the runway. Simultaneously applying into-wind aileron to stop the windward wing pitching up obviously requires a fair amount of co-ordination, as it does to get all these things right.

Once the aircraft has touched down, the nose is lowered towards the runway until the nose-wheel touches down. Simultaneously, the non-handling pilot will move the reverse levers up to the interlock, which makes the cowls translate on the engines, and the blocker doors then move across, blocking the fan duct. This drags air from the fan, through a series of cascades – basically removing effective forward thrust. There is not that much of decelerative component there. A pre-programmed autobrake setting would also have been selected prior to the approach, and this will give a programmed amount of deceleration, so that we end up at the appropriate point on the runway to turn off. Once we turn off, the after-landing check is executed, which involves bringing the flaps in, lowering the speed brakes, starting the APU, and basically switching off any items which are not required once we have turned off the runway, such as the strobe lights and the transponder. The taxi in towards the gate, and at the appropriate time, make a P.A. announcement telling the cabin crew to select the doors to manual so that it is safe for groundcrew to open doors without the risk of the slides inflating and causing injury.



Speedbird 2019 lands at 14.28 local time and is directed to its stand (which incorrectly displayed '777' – this was the first flight of a BA 747 into DIA). Alan Emery taxies in perfectly, the engines are shut down and Captain Downey flicks the switches on the overhead panel. BNLA will be prepared for another crew, and flown back to the UK on the next scheduled flight. After a lay-over in Denver, Captain Downey and his crew will board another 747 for an early evening departure for London-Gatwick. Author

British Airways' 747-400 Inspection and Aircraft Maintenance Schedule (AMS)

Checks	*Frequency*	*Time taken*	*Details*
Transit Check	Every departure (Not Heathrow)	½ hour	Two engineers and a flight-crew member. Exterior check of the 747 and engines for damage or leakage. Specific checks on listed items such as brake and tyre wear.
Ramp One	Daily	3 hours	Four engineers. Transit check plus additional checks on engine oil levels, tyre pressures, 747 external lighting, cabin emergency equipment, engine health monitoring systems and assessment of technical log entries.
Ramp Two	Every 190 flying hours	3 hours	Four engineers. Transit and Ramp One checks plus checks on APU and component oil levels, engine component oil levels, cabin interior condition and windows.
Ramp Three	Every 540 flying hours	3 hours	Six engineers. Transit, Ramp One and Two checks plus replacement of hydraulic-systems filters, checks on cockpit and cabin seating and attachments, sterilization of water system and detailed inspection of system filters. More detailed inspections on items covered in previous checks, including avionic systems and standby power systems. Batteries changed.
Service One	Every 1,060 flying hours	Two shifts (about 16hr)	Fifty engineers. During overnight stopovers at a maintenance base. All previous checks plus partial stripdown of structure and engines for detailed inspection. Replacement of worn components and soiled or damaged cabin equipment and furnishings. Servicing of undercarriage struts.
Service Two	Every 2,120 flying hours	Three shifts	Fifty engineers. All above checks plus additional and more detailed inspections of specific areas. External wash of aircraft, system clarification function checks, and deep cleaning of cabin water and waste systems.
Service Three	Every 3,875 flying hours	Four shifts	Fifty engineers. All of the above, plus detailed inspection of flying controls, structure and engines. Fluid levels drained and refilled in major mechanical components. Aircraft washed, avionics systems integrated check. Cabin condition assessed and repaired in depth.
Inter Check	Every 6,360 flying hours	7–8 days	160 engineers. Detailed inspection and repair of 747, engines, components, systems and cabin, including operating mechanisms, flight controls, structural tolerances.
Inter Check Two	Every 12,720 flying hours	8–9 days	160 engineers. All of the above, plus additional system function checks.
Major Service	Every 24,000 flying hours, or every five years if sooner	20–25 days	180 engineers. An intensive operation which involves major structural inspections including attention to fatigue corrosion. The 747 is virtually dismantled, repaired and rebuilt as required, with systems and parts tested and repaired or replaced as necessary. Corrosion prevention and control tasks are also carried out.

(BA Avionic Engineering Ltd (BAAE) is located at a purpose-built 140,000sq ft (13,000sq m) facility near Llantrisant, mid-Glamorgan, Wales, opened in 1993.)

G-CIVM Nami Tsuru, **or Speedbird 2018, will make the return flight to Gatwick, and the first task for Alan Emery is to carry out the walk-around check. The swirling design in blue and grey on the tail is a traditional Japanese art form known as 'Nihon Ga', the original painting on which the design is based being entitled 'Waves and Cranes'.** Author

(continued overleaf)

British Airways' 747-400 Inspection and Aircraft Maintenance Schedule (AMS) *(continued)*

Snr 1st Off Alan Emery checks the nose-wheel gear for possible hydraulic leaks, looks over the tyres for possible cuts and signs of wear and tear, and looks inside the RB.211 fan engine to inspect the blades; he then checks the rear cargo hold. He also examines the control surfaces, checks that pitots and static vents are uncovered and that access panels are secured, as well as checking for signs of oil leaks, and for skin and surface damage caused by foreign object damage (FOD). Author

Captain John Downey goes through the pre-flight check-list with Fg Off Dominic Boyle for the 16.00 departure to London-Gatwick. Because of the outside air pressure at Denver (which is 5,300ft (1,600m) above sea level), the Autostart for two engines cannot be used; instead a manual start of each engine is carried out. Author

(Right) Captain Downey taxies G-CIVM out of Denver. Although the pan at DIA is huge (from the flight deck it looks certainly as wide as all eight lanes of the M25), he and Dominic Boyle keep a sharp eye out for other aircraft. Traffic levels at DIA have risen to more than 35 million passengers in 1998, surpassing Stapleton's record of 34 million in 1997. United Airlines now has 315 daily departures at DIA and wants 400 in two years, just thirty-five departures less than United's largest hub, Chicago O'Hare Airport. Author

(Below) Three pilots on the flight deck gives three pairs of eyes shortly before and during take-off. After rotate at 16.15 hours, while Captain Downey and Dominic Boyle pilot the aircraft, Alan Emery re-checks the fuel calculations. The aircraft is travelling at 525 knots, helped by a 35-knot tailwind leaving Denver. Author

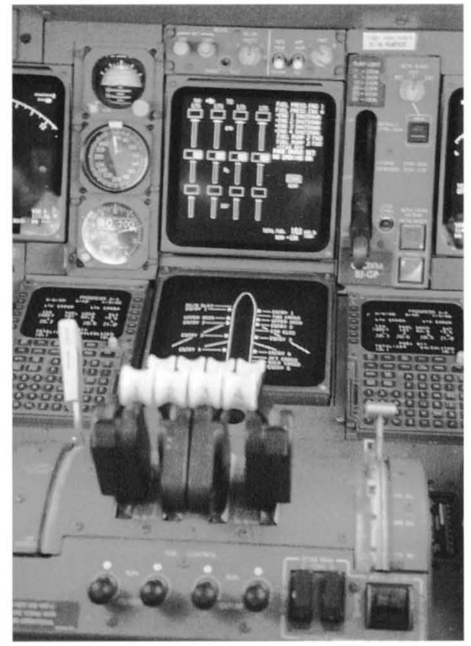
Track, heading, wind and distance on the last leg of the flight into Gatwick show up on the captain's navigation display (ND) or EHSI (electronic horizontal situation indicator). Descent speed is 250 knots, and height 11,400ft (3,475m). British Airways' standard operating procedure (SOP) is to fly clean for as long as possible, 10 knots above Flap One speed (220 knots). Author

(Below) **Runway 08 (right) at Gatwick on Speedbird 2018's approach. Dominic Boyle piloting the 747-436, picks up the glide scope level at 3,000ft (900m) 12 miles (19km) out, and is over the threshold at 142 knots.**

(Opposite page, top) **Captain Downey then gets a feel of the controls at 1,000ft (300m) and brings the aircraft in for landing. Gear is down at 7.45am and he puts the aircraft down with a slight flare of 1R-2° (the 747 is such a stable platform that pilots can flare a few feet (20–50ft/6–15m) off the ground.** Author

(Opposite page, bottom) **Speedbird taxis back after landing at Gatwick.** Author

(Above) **Eyes are peeled looking for Remote Stand 171.** Author



(Right) **At Remote Stand 171 Speedbird 2018's engines are shut down. The two centrally located engine indication and crew alerting system (EICAS) display units show the fuel pressures, and that all four engines are shut down. The total fuel remaining is 22,266lb (10,100kg). Chock to chock, it has taken 9 hours 2 minutes since leaving Denver, Colorado.** Author

British Airways' technicians working on a RB.211-524G at BA Avionic Engineering Ltd (BAAE). This purpose-built 140,000sq ft (13,000sq m) facility near Llantrisant, mid-Glamorgan, Wales, was opened in 1993. Rolls-Royce

CHAPTER TWELVE

Stretched to the Limits

Apart from the short-performance 747s in the Asia-Pacific network of operations, low-level studies conducted in the late 1980s indicated that there was a requirement for another special performance airliner, but at the very opposite end of the scale to the SP. In the 1980s the airline passenger market had not been ready for a big-winged and stretched behemoth; by the end of the decade, though, a combination of high economic growth in Asia (where air travel in 1996 was soaring by up to 10 per cent a year, twice the rate in the West), and dramatic new advances in aeronautical design, indicated that for the first time there seemed a very real chance that a re-winged and stretched 747 could become a sustainable reality. Airlines now looked to manufacturers to produce an airliner capable of carrying between 600 and 800 passengers at distances of 8,625 statute miles (13,878km) and greater.

In 1988, the product development group at Boeing unveiled its potentially re-winged and stretched 747 design, the '47-X'. It was made possible by features previously denied to earlier development engineers: more efficient engines, composite materials and improved systems were now available. Most important of all, high-aspect wing designs were now so far advanced that reduced sweep angle could be used, and huge spans in the region of 240 to 260ft (73 to 79m) were possible. Bigger wings meant longer fuselages, and a fuselage stretch of about 24ft (7m) using two 12ft (3.7m) plugs was therefore possible. Longer fuselages meant greater payload, though the new wing would increase gross weight to more than 1,000,000lb (453,600kg). In 1991 United Airlines asked Boeing to carry out studies of an all-new long-range airliner capable of carrying 650 passengers over the vast tracts of the Pacific.

Early in 1992 Boeing invited United and other airlines to form a select group to study data on proposed new large aircraft (NLA) designs provisionally called the N650 or 747-X. In actuality, the designs involved well in excess of one hundred different configurations, the largest of which bore a wing 290ft (88m) wide – 79ft (24m) wider than that used on the 747-400. With wings this wide, folding wing-tips, as developed for the 777, would have to be used if the aircraft was to use gates existing at airports. Take-off weights peaked at an incredible 1.7 million pounds (771,120kg) (the -400's gross weight by comparison, is around 870,000lb/394,632kg), with seating for up to 750 passengers in three classes. These would have to be accommodated in rows of seats twelve abreast on the lower deck, and eight to nine abreast on the upper deck. The high gross weight would have to be redistributed using a new, main-gear design of up to twenty-four main wheels mounted on four main trucks. Even so, after studying the structures of runways and taxiways at seventy of the world's leading airports, it was reckoned that seventeen runways would have to be strengthened and resurfaced. In fact the 747-X was so big that TV cameras, which initially were thought necessary on the very first 747, would have to make their reappearance, to help the pilots during taxiing at airports.

There were many other important considerations too, not least the greatly increased loading and unloading times, additional meals, and galleys that would be needed, the bigger door sizes and increased fuel, and so on – but there was also, of course, the usual major stumbling block, the all-important question of suitable engines to power the huge beast! Not only had they to be capable of about 85,000lb (38,556kg) of thrust in the climb to lift a 650-seat 747-X into the air, they also had to conform to 'Stage 3 minus' noise parameters, and be capable of expansion to power the larger 800-seat 747-X version. The Treble Seven was to show that engines capable of developing the high climb-thrust needed *were* possible. The three leading engine manufacturers – Pratt & Whitney (PW4000 series); General Electric (GE90 series) and Rolls Royce (Trent 800 series) – developed more efficient and quieter turbofans to power the Boeing 777. For the initial aircraft, these engines are rated in the 74,000–77,000lb- (34,306–34,930kg-) thrust class. For the longer-range model and the 777-300, these engines are capable of thrust ratings in the 84,000–90,000lb (38,100– 40,824kg) category. These engines could be developed to even higher thrust ratings, depending on future payload and range requirements. Key factors in their performance are new, larger-diameter fans with wide-chord fan-blade designs, and bypass ratios ranging from 6-to-1 to as high as 9-to-1.

Ironically, while the engine technology, for the first time in the 747's operational career, would become available to power this next generation of airliners, there was another technological stumbling block to overcome. By the middle of 1992 two of the three main proposals that emerged from the myriad selection of big-winged and stretched 'super jumbo' designs were stretched developments of the 747-400, but they retained the existing wing design, and consequently they would be penalized by the all-too-familiar range restrictions. The basic stretched version, with an increased length of 24ft (7m) achieved by inserting two 12ft (3.8m) plugs fore and aft of the wing, an empty weight of 438,000lb (198,677kg) and seating for up to 480 passengers, would have at least 435 miles (700km) less range than the -400.

The third increased stretch variant, some 23ft (6.9m) longer than the -400, and which could potentially carry up to 630 passengers, would have at least 870 miles (1,400km) less range than the -400, and fly only about the same maximum distance as the -200B. Wing-tip winglets (as on the 747-400 series), wing-root extensions and composite materials all offered a modest increase in range, but without a complete wing redesign, it was impossible to dramatically redevelop the 747 configuration further. The third option, therefore – an all-new double-deck NLA – introduced a complete departure from the

established 747 design by having four engines mounted on a 258ft (79m) wide high-aspect-ratio-wing, the wing type favoured for use on new-generation airliners such as the Airbus 300 and 310.

NLA and Other Projects for the Nineties

One problem with the reduced wing thickness/chord ratio (span, or length, relative to its chord, or breadth) and high sweepback of the wings as used in the 747 series, is that almost all the lift comes from the upper surface just behind the leading edge. The violent acceleration across this area produces intense lift, or suction, but its shape results in supersonic speed being attained at a very low mach number, and shock waves build up and cause drag. In the 1960s a wing profile with a reduced curvature, or flatter top, a bulged underside and down-curved trailing edge, was found to be more efficient than a thinner wing with sweepback. This 'super-critical' (or 'aft-loaded') wing is more efficient in the cruise as the aft-loaded cross-section distributes lift more evenly across the upper surfaces. This creates improved lift because the acceleration across the top of the wing is milder, the onset of supersonic shock-waves is delayed, and as a consequence, the cruising speed is greatly increased and the fuel savings are enormous. (Whereas the 707 has a ratio of 7, the A310 reaches 8.8 and the A320, 9.4.) A thicker wing also enables more fuel to be carried, and because much thinner skins are used, there is a marked saving in weight. (The higher landing and operating empty weights of the 747-X would have required the use of a thicker-skinned wing then under development for the -400F.)

In view of the range penalties associated with the stretch developments on the 747-based versions, and the advantages of the all-new aircraft, most in the airline group not surprisingly favoured further study of the NLA. Other aerospace companies, notably Airbus Industrie in Europe, and McDonnell Douglas in the US, were, by 1992, showing signs of unleashing their own long-range, high-capacity aircraft. (Airbus carried out studies into a 600-plus ultra high-capacity aircraft (UHCA) by mating two A340 fuselages together side by side, and an 800-seater version was even considered. However the projected MD-12 double-deck, long-range design series, planned to become available in six versions and carrying 430–511 passengers over distances of 6,950 miles (11,183km) and 6,260 miles (10,072km) respectively, never left the drawing-board because of the failure to cement links with proposed partner Taiwan Aerospace.) Boeing's all-new double-deck NLA, meanwhile, would offer accommodation for 600 passengers in its primary 235ft- (72m-) long configuration, while the stretched configuration, which was more than 300ft (90m) long, would carry more than 750 passengers. Range was anticipated to be in the order of 6,957 miles (11,194km).

Not for the first time in developments of this magnitude, cost was proving prohibitive. At the beginning of 1993 Boeing tried to spread the huge investment in the NLA by entering into partnership with a consortium made up of four European aerospace companies to develop a very large commercial transport (VLCT). (The potential market for such a large aircraft was finally deemed too small, and in July 1995 the VLCT project was put on hold.) By late 1993, meanwhile, Boeing had arrived at five distinct single- and double-deck NLA configurations, the largest of which could carry 630 passengers. However, having got this far, the NLA finally went the same way as the VLCT when it was decided that the market for the all-new aircraft was too small for the huge investment needed.

Boeing's NLA project is still no more than a design proposal. Rolls-Royce

The 747-500X/600X/700X Projects

It is often said that the only replacement for a Dakota is another Dakota, and the only improvement on the C-130 Hercules is the next Hercules. By the mid-1990s most of the leading airlines were of the opinion that the only way to improve the 747 was a revamped, re-winged 747, one to carry fewer, not more, passengers than the abandoned NLA, UHCA and VLCT projects. Boeing and the leading carriers knew that the market for very large airliners was not big enough to warrant spending millions of dollars on developing or operating such massive aircraft. Yet soon almost twenty carriers, principally British Airways and Singapore Air Lines, and others with substantial 747 fleets, were showing great interest in reviving the 747-X. Not for the first time in the 747's long and outstanding career, commonality was a key factor in the decision-making process, not only for the airlines, but for Boeing itself. While the advantages of the 747-X for existing 747 carriers are obvious, the derivative design would also enable Boeing to use many tried and tested components designed for the 747-400, and the 777. (The latter, the world's largest twin-jet, was first delivered in May 1995.) This is not to say that the issue was as clear-cut as this: in a way, Boeing were by now a victim of their own success. On the international routes their medium-sized 757 and 767 twins were proving more economical for the airlines than a half-empty 747. Whilst commonality with the design of the 747's systems offered many cost savings, the 747-X would require a super-critical wing, and also some potential 747-X customers wanted a 747 with appreciably more range, while others wanted much more payload capacity than the 747-400.

Boeing's approach to achieving these aims, while at the same time keeping development, production and end-user costs down, was to use avionics and flight-deck architecture developed for the 747-400 and 777. The super-critical wing for the 747-X would be a 40 per cent scaled-up version of the aft-loaded structure used on the 777, and the gear would be the same six-wheel wing main undercarriage used on the widebodied twin-jet. The engines would be a derivative of the Trent 800 which powers the 777. No one airline has exactly the same requirements as another, and while this had always been the case with the 747, it was not about to change with the 747-X. Predictably, the gross weight of the -500X and -600X began to rise sharply with increases in the payload demanded by the airlines, and engine-thrust would have to rise accordingly.

Engine Propulsion

Finally, a powerplant that was capable of producing between 77,000–80,000lb (34,927–36,288kg) of take-off thrust (a higher ratio of climb thrust to take-off thrust was needed to provide a higher initial cruise altitude than that of existing 747s) was identified. (Historically, thrust requirements have increased typically by up to 4 per cent a year.) In 1995 there was only one engine entirely suitable, and that was the Trent 800 series. Although four Trent 800s would be too powerful for the 747 (in January 1995 this engine was certificated to 90,000lb (40,825kg)), by derating them, they would then be ideal for the 747-X. The Trent also had two other distinct advantages; it would meet the all-important noise regulation requirements, and the 110in- (280cm-) diameter fan was small enough to fit underneath the 747-X's new wing.

A big fan engine with a high bypass ratio of up to thirteen presents additional problems to the plane makers. Putting four engines with 160in (406cm) fans – 13ft (4m)! – on a future, very large aircraft, is a nightmare scenario: the size of the landing gear and the additional weight penalty this incurs will be enormous. Another issue that confronts engine designers when planning a powerplant with a bypass ratio of nine and above is the use of a gearbox versus direct drive. John Cundy, writing in 1995, explains:

> A gearbox allows optimization of the rotational speeds of the fan and the low-pressure turbine that drives it. With direct drive, you have to increase the number of low-pressure stages. For example, an engine with a bypass ratio of ten would require six low-pressure stages. But an engine having a ratio of thirteen would need only three stages if it had a gearbox.
>
> However, the reduction gear power for a 100,000lb- (45,360kg-) thrust engine is 80,000 horsepower. With an assumed transmission efficiency of 99 per cent, the waste heat to be managed in the cooling systems is high – 800hp – that's equivalent to the combined power of eight 1.5 litre cars! The trade lies between the weight and cost of the direct drive's increased number of low-pressure stages, and the gearbox, with its oil and cooling systems but many fewer stages.

Left floundering in Rolls' wake, General Electric and Pratt & Whitney announced on 8 May 1996 that they were jointly developing a new powerplant for the 747-500X and -600X. The proposed GP7176 turbofan would involve GE manufacturing the high-pressure part of the engine, including a GE-developed double annular combustor to conform to the latest environmental regulations, and P&W would take responsibility for the low-pressure area, including the 110in- (280cm-) diameter fan. Rolls responded in July with the announcement that they were developing the Trent 900 for the 747-X. So what had started out as an off-the-shelf and therefore low-cost option had become a race to develop an all-new engine for the 747-X, and this only succeeded in substantially increasing the cost of the new airliner.

747 Finale?

By late 1996, even though Boeing announced study plans for an even bigger aircraft, the 747-700X, which would carry 650 passengers, it looked as if the 500X/600X project would go the same way as the NLA and VLCT studies. Although Boeing had made every effort to keep expenditure down (the operating costs of the 747-X were 10 per cent lower than that of the 747-400) the development costs had escalated from about $1 billion to a staggering $7 billion, and the basic 747-X was expected to cost in the region of $200 million. This was way too high when compared to the 'sticker' price of high-tech, fuel-efficient, widebodied twins like the 757/767, and the Airbus Industrie A300 series. Apart from the initial outlay, airlines had also to consider the operating costs of the 500X and 600X when compared to the more economical widebodied twins such as the 767-200/300ER and A310 and A300-600R.

The days when the transatlantic and long over-water Pacific routes were entirely the domain of the four-engined airliner were coming to an end. Now they were fast being dominated by the widebody twins, which because they could fly directly to their destinations, had no need to use the traditional hubs at, say, New York or London to transfer their passengers. Airlines, conscious of the fact that it was more

The 747-X would be a 40 per cent scaled-up version of the aft-loaded structure used on the 777, and the engines would be a derivative of the Rolls-Royce Trent 800 which powers the 777. In July 1996 Rolls announced that they were developing the Trent 900 for the 747-X. The Trent was successfully tested on the N7470 flying testbed in 1995 in preparation for the start of the Trent-powered 777 flight-test programme. The programme accumulated twenty hours in five flights and included a full 90,000lb- (40,824kg-) thrust take-off. Rolls-Royce

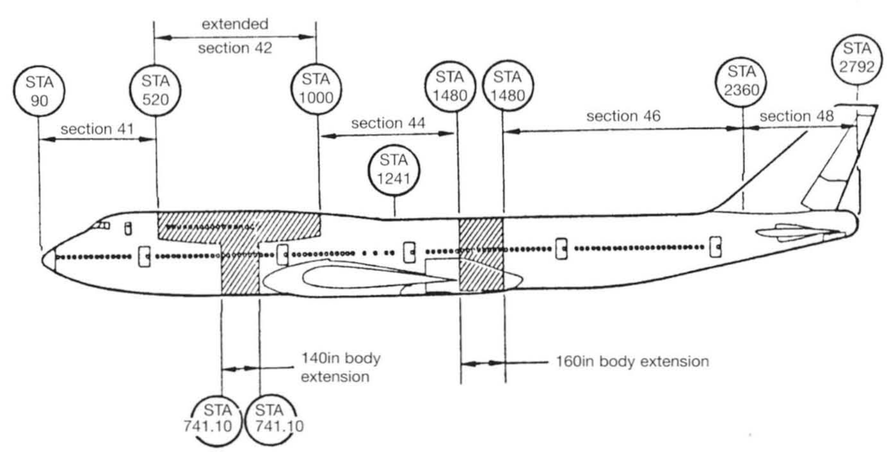
There will come a time when the already highly congested hubs will simply be unable to cope with the sheer weight of aircraft movements and slots that are possible, and much bigger airliners such as the NLA could provide a solution. Schiphol Airport

profitable to operate medium-size twins on these point-to-point services than to fly sometimes less-than-full 747s, saw the 747-X as being uncompetitive in the new order. Taking all of this into consideration, Boeing publically announced, on 20 January 1997, that the 747-X was being halted. Development energies instead would concentrate on the proposed 767-400ERX and 777-200X/300X long-range, high-capacity widebody twins.

It therefore remains to be seen whether the 747-400 is the last of its generation. (In 1998 eighteen 747s were produced and in 1999 fourteen were finished.) Although the technology is clearly available for a 600-seat airliner powered by four 80,000lb- (36,288kg-) thrust engines to become reality, in view of the relatively high operating costs involved, it is difficult to envisage it happening in the new millennium. If one were to be built, it would in all probability emerge from the fertile ground at Everett or from the Airbus consortium in Europe.

Boeing has such a widely diversified commercial and military presence in the world aerospace industry that even if it now cannot always bend and shape this market, it can certainly adapt to it. As of 31 March 1999, the total Boeing Commercial Airplane Group jet transport orders – including 1,293 747s, of which 1,203 were delivered – stood at a staggering 14,267, of which 12,604 had been delivered. Commercially, if this means building fewer 747s while delivering more widebody twins in competition with the European consortium, and bidding time on projects such as the 747-X or NLA, then so be it. Included in the 31 March 1999 totals are orders for 4,256 737s (3,331 delivered), 966 757s (853 delivered), 864 767s (740 delivered, and the McDonnell Douglas series, MD11

While supersonic aircraft such as Concorde continue to offer high-speed travel, mass transportation will remain the domain of aircraft such as the 747. In the mid-1990s British Airways calculated that by 2010 it could double the number of passengers using Heathrow Airport to 36 million passengers, by increasing its fleet by just twelve 747-X or NLA aircraft.



'Super Jumbo' stretched development of the 747-400. Boeing

(220 ordered, 187 delivered), MD80 (1,191 ordered, 1,167 delivered), and MD90 (134 ordered, 103 delivered). As long as airlines are happy to buy wide-body twins that they know they can fill and operate economically, Boeing will obviously continue to build them.

There will come a time very soon however, when the already highly congested hubs such as London's Heathrow and Gatwick, Los Angeles and New York, will simply be unable to cope with the sheer weight of aircraft movements and slots that are possible. Perhaps one of the ways of keeping pace with, and meeting the rising passenger loads without filling the air-lanes with an increasing number of aircraft, is to build much bigger airliners. In the mid-1990s Heathrow airport alone was handling about 18 million passengers a year. British Airways calculated then that it could double the number of passengers using the airport by 2010 by increasing its fleet by just twelve 747-X or NLA aircraft.

Perhaps, therefore, by the end of the next millennium we will not have seen the last of the superlative 'jumbo'.

APPENDIX I

747 Programme Chronology

1963	
Spring	Engineering group is organized to plan an aircraft which will meet passenger and cargo growth predicted for the 1970s.
1966	
March	Boeing board of directors decided to proceed on the 747 programme.
April	Pan American World Airways announces it will purchase twenty-five Boeing 747s.
June	780 acres acquired adjacent to Paine Field, Everett, Washington, for 747 manufacturing plant.
September	Airline orders for new superjet reach value of $1.8 billion.
1967	
January	Production operations for 747 begin at the Everett plant.
1 May	Everett assembly building – the world's largest – is activated.
Late autumn	First nose section arrives at Everett plant from Wichita Division; components manufactured by major subcontractors begin arriving.
1968	
Mid-June	JT9D test engine flown by Pratt & Whitney on B-52 testbed.
30 September	First 747 completed and rolled from factory.
November	Boeing announces a longer-range 747 capable of greater payloads, to be designated 747B. Freighter and convertible versions also to be offered.
1969	
9 February	Initial flight of first 747 completed. Flight-test programme begins.
30 December	Boeing 747 certificated by US Federal Aviation Administration for commercial passenger service.
1970	
21 January	Boeing 747 commercial service begun by Pan American World Airways, on New York–London route.
16 July	Millionth passenger carried on 747s.
30 September	First 747-2OOB, the eighty-eighth 747 produced, rolled out at Everett.
12 November	747-200B sets world heavyweight record, taking off from Edwards AFB, CA, at 820,700lb (372,269kg) gross weight, 500,700lb (227,117kg) being fuel, flight-test equipment and payload.
23 December	747B certificated.
1971	
12 February	Boeing 747 equipped with fail-operative triple-autopilot system certificated for operation in Category IIIA conditions, with runway visual range only 700ft (213m) or about three aircraft lengths.
26 February	One-hundredth 747 delivered.
July	First 747 to have extended upper deck (line number 147) handed over to Qantas.
December	Delivery of 747s with new sound-suppressing nacelles begins.
1972	
8 March	First 747F freighter, for Lufthansa German Airlines, certificated.
September	747s log 1,000,000 flight hours.
30 October	Boeing announces it will produce short-range version of the 747, Japan Air Lines (JAL) announces order for four of the new version, designated 747SR.
1973	
17 April	747C convertible passenger-cargo airliner certificated by FAA and delivered to World Airways, largest charter carrier.

18 April — First delivery of a JT9D-7AW engine, capable of 46,950lb (21,297kg) thrust (dry), or 48,750lb (22,113kg) with water injection, fitted to -200B line number (the 200th 747 built) for El Al.
August — Boeing announces it is proceeding with development of a 'Special Performance' 747.
10 September — Pan American World Airways becomes the first airline to order the 747SP (Special Performance) extra-long-range jetliner.
7 October — The first 747SR (Short Range) enters service with Japan Air Lines (JAL) between Tokyo and Naha, Okinawa.

1974
15 February — SABENA Belgian World Airways is first carrier to get 747 with side cargo-door modification.
5 July — KLM-Royal Dutch Airlines orders first 800,000lb (362,880kg) gross weight 747B powered by General Electric CF6-50E engines.
29 December — Qantas 747-238B *City of Melbourne* (fitted with 369 seats) evacuates 674 passengers (306 adults, 328 children and 40 infants) from Darwin to Sydney, following the devastation caused by Cyclone Tracy.

1975
8 April — 747 approved for thirty-two passengers on upper deck when fitted with left side upper deck emergency exit.
19 May — First 747SP (Special Performance) airliner rolls out.
27 June — British Airways orders 747s powered by Rolls-Royce RB211.524 engines rated at 50,100lb (22,680kg), the third 747 engine-type option.
4 July — First 747SP makes initial flight, completing the 'most ambitious' test series ever by a Boeing jetliner. Top speed attained was Mach 0.92.
October — 747 fleet carries 100-millionth passenger.
10 December — Boeing 747SP lands at Boeing Field, Seattle, completing a twenty-nine day, 72,152-mile (116,092.5km) worldwide demonstration tour during which it visited eighteen cities in eighteen countries, and made three non-stop flights of more than 7,000 miles (11,263km).

1976
4 February — The 747SP is certificated by the Federal Aviation Administration for commercial use.
5 March — First 747SP delivered, to Pan American World Airways.
24 March — A South African Airways 747SP landed in Cape Town following a 10,290-mile (16,557km) non-stop flight from Paine Field, Washington, setting a world distance record for commercial aircraft.
1–3 May — A new around-the-world record was set by a Pan American World Airways 747SP (*Clipper Liberty Bell*) when it landed at New York JFK airport after a two-stop, 22,864-mile (36,788km) flight. Elapsed time totalled 39 hours 26 minutes. En route stops were at Delhi and Tokyo.
1 November — A new world record for maximum mass lifted to 6,562ft (2,000m) was claimed for the 747 when a 747B powered by Rolls-Royce RB211 engines took off from Lemoore Naval Air Station, California, at 840,500lb (381,251kg) and climbed to the required altitude in 6 minutes 33 seconds.

1977
30 September — The worldwide fleet of more than 300 747s passed the five million flight-hours' mark.
28–30 October — Pan Am 747SP (N533PA, specially named *Clipper New Horizons* for the occasion, to mark the airline's fiftieth anniversary) set a new speed record for an around-the-world flight, passing over both poles: San Francisco–London–Cape Town–Auckland–San Francisco, in 54 hours 7 minutes and 12 seconds for the 26,706 mile (42,970km) flight, breaking the previous record established twelve years earlier by a modified 707 by 8 hours 20 minutes.

1978
21 December — First 747-100B delivered, to All Nippon Airways.

1979
11 October — 400th delivery, a 747-200B to Aerolineas Argentinas.
21 December — 100th main deck cargo 747 delivered, a 747C to Transamerica Airlines.

1980
31 January — First 550-passenger 747 delivered, an SR to Japan Air Lines (JAL).
11 June — Boeing announces a new version, the 747-300 (extended upper deck). First deliveries begin in 1983, to Swissair.
19 December — 500th rollout, a 747-200B for SAS.

1981
15 December — Largest 747-300 order; eight for Singapore Airlines.

1982
21 September — First 747-300 rollout (Swissair livery); enters five-month flight-test.

1983
March — 747-300s enter commercial service (Swissair and UTA).

1984
July — Captain Lynn Rippelmeyer of People Express becomes the first woman to captain a 747 across the Atlantic.

1985
October — Boeing announces twelfth commercial version of the aircraft; the 747-400 will roll out in early 1988, with first deliveries in late 1988.

1986
9 April — Boeing announces a 747-400 Combi version.

1988
26 January — Rollout of 747-400.
January — Clay Lacy sets a 36 hour 54 minute around-the-world speed record in 747SP-21 N147UA (c/n. 21548) christened *Friendship One.* The flight (routing through Seattle–Athens–Taipei–Seattle) raises more than $500,000 for children's charities of the world.
29 April — First flight of the PW4056-powered 747-400.
27 June — The first 747-400 set a new world record by taking off at a gross weight of 892,450lb (404,815kg).

1989
9 January — PW4056-powered 747-400 certificated by the FAA.
26 January — PW4056-powered 747-400 delivered to Northwest Airlines, entering service on the Phoenix–Minneapolis route on 9 February.
18 May — First GE-powered 747-400 delivered to KLM.
26 May — 747-400 completes the longest engineering flight in Boeing Commercial Aircraft history, lasting more than fourteen hours as cruise performance is evaluated.
8 June — Cathay Pacific received first Rolls-Royce-powered 747-400.
June — First 747-400 Combi completed.
September — First 747-400 Combi handed over to KLM.
13 September — 747-400F programme launched.

1991
March — First -400D (for JAL), the 844th 747 built, flew for the first time.
During the year — El Al 747-200C Combi, specially converted to passenger configuration with 760 seats, carries more than 1,200 Ethiopian Jewish settlers from Addis Ababa to Tel Aviv, Israel, in Operation *Solomon*, a top secret operation to airlift 14,000 Ethiopian Jews to Israel before the Ethiopian capital fell to rebel troops. Two other standard passenger-configured El Al 747s, with normal seating for 454, carried 920 passengers each. The rest of the operation was carried out using four 767s, two 757s, and eight Israeli Air Force 707s.

1993
25 February — First -400F (the 968th 747 built) rolled out at Everett.
4 May — First flight of the 747-400F (for Cargolux).
10 September — Rollout for the 1,000th 747 (for Singapore Air Lines) at Everett.

1998
6 July — Cathay Pacific's 747-467 B-HUJ first airliner to land at Hong Kong's new Chek Lap Kok International Airport, after a record-breaking world distance record for the longest commercial flight, from New York, over the North Pole, a distance of over 6,582 miles (10,590km), lasting 15 hours and 24 minutes.

747 Airframe Losses

DATE	REG	SERIES	CARRIER	FATE
6 Sept 70	N752PA	121	Pan Am	Blown up by terrorists, Cairo, Egypt, following hijack
24 July 73	JA8109	246B	JAL	Blown up by terrorists, Benghazi, Libya, following hijack
20 Nov 74	D-ABYB	130	Lufthansa	Took-off from Nairobi, Kenya, with leading-edge flaps retracted
12 June 75	F-BPVJ	128	Air France	Destroyed by fire after undercarriage fire, Bombay, India. No casualties
27 Mar 77	N736PA PH-BUF	121 206B	Pan Am KLM	N7736PA struck by PH-BUF in fog at Los Rodeos, Tenerife, CI, when the KLM aircraft took off prematurely
1 Jan 78	VT-EBD	237B	Air India	Dived into sea off Bombay, following ADI failure, killing all 213 on board
19 Nov 80	HL7445	2B5B	Korean Air	Touched down 300ft (90m) short of runway in fog at Seoul, RoK. Fourteen passengers died
31 Aug 83	HL7442	230B	Korean Air	Shot down, Sakhalin, Sea of Japan, by Soviet Air Force Su-15
27 Nov 83	HK-2910	283M	AVIANCA	Nr Madrid, Spain. Inaccurate approach
16 Mar 85	F-GDUT	383	UTA	Caught fire, Paris CdG, France
23 June 85	VT-EFO	237B	Air India	Terrorist bomb in the forward cargo hold, Atlantic Ocean, off Ireland while en route from Montreal–London
12 Aug 85	JA8119	SR-46	JAL	Crashed into Mt Osutaka, Japan, after rupture of the aft pressure bulkhead following improper repair
2 Dec 85	F-GCBC	228M	Air France	Ran off runway at Rio-Galeao, Brazil, and damaged beyond economical repair
28 Nov 87	ZS-SAS	244M	SAA	Intense fire developed in the right-hand forward pallet while en route from Taipei to Mauritius; crashed into Indian Ocean
21 Dec 88	N739PA	121/SCD	Pan Am	Exploded over Lockerbie, Scotland. Terrorist bomb
19 Feb 89	N807FT	249F	Flying Tigers	In-flight collision with terrain, Puchong, Malaysia
7 Apr 90	VT-EBO	237B	Air India	Landing accident, New Delhi, India. Destroyed by fire
2 Aug 90	G-AWND	136	BA	Destroyed by shelling, Kuwait Int Airport
29 Dec 91	B-198V	2R7F	China Airlines	Number three engine separated from wing soon after take-off, Taipei, Taiwan
4 Oct 92	4X-AXG	258F	El Al	Number three engine separated from wing, crashed Bijlmermeer, Netherlands
12 Sep 93	F-GITA	428	Air France	Veered off runway at Papeete
4 Nov 93	B-165	409	China Airlines	Overran runway, Hong Kong, Kai Tak. Instructional airframe at Xiamen, PRC
20 Dec 95	N605FF	136	Tower Air	Aborted take-off at New York JFK. Aircraft cannibalized, Jan 1997
17 July 96	N93119	131	TWA	Lost in Atlantic off Long Is., NY, 11½ mins after take-off. Suspected fuel-tank ignition
12 Nov 96	HZ-AIH	1688	Saudi Arabian Airlines	Mid-air collision Charkhi Dadri, 30ml (50km) W of Delhi, India, with IL-76 UN-75435 of Kazakstan Air Airlines
6 Aug 97	HL7468	385	Korean Air	In-flight collision with hills on approach to Agana, Guam, Micronesia
6 Mar 99	F-GATN	2B3F	Air France Asia Cargo	Madras-Chennah Airport, India. After travelling 700ft (200m) along runway, nose-wheel collapsed, overran runway and was destroyed by fire. Five crew escaped (one injured jumping to ground)

Index

The introduction of the Boeing 747 into service in 1970 heralded a new era in air transport. The first wide-bodied airliner and the first to be powered by turbofans, it immediately captured the imagination of the press who dubbed it the 'Jumbo Jet'. Capable of carrying up to 500 passengers, it drastically reduced seat per mile costs and, significantly, put affordable intercontinental travel within the reach of everyman.

Martin W. Bowman tells the story of the highly successful Boeing 747 series in this welcome addition to the Crowood Aviation Series.

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